LEARNING AND THE MIND BRAIN:

PRIGOGINE IN THE CLASSROOM

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Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF EDUCATION
July, 1998

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PREFACE

The real cycle you're working on is a cycle called "yourself."

- Robert Pirsig, 1974, Zen and the Art of Motorcycle Maintenance

One spring morning, a very special student caringly gave me a funny-shaded purple book about Zen and motorcycles. I didn't think I liked either one—Zen or motorcycles! In fact, motorcycles were the only things my boys, now grown, were not allowed to ride. And Zen, what can I say? After enrolling in a doctoral program and looking over the books and assignments to be read for that semester, what I did not need was another book!

I carefully placed the gift on the shelf to be discovered another day. However, for some reason, I picked it up again and began reading. I wondered who "Phaedrus" was. I began reading to my husband (who is a real mechanic). On hearing the words aloud, I saw the scientist, English teacher, parent, journey-taker me riding on that famous mythological journey. This gift of self-knowledge began with one of my students who understood me better than I understood myself.

I read Pirsig's (1974) Zen and the Art of Motorcycle Maintenance and then read Einstein's Space and Van Gogh's Sky (Leshan & Margenau, 1982) as a class assignment. It became apparent while both books had similar goals but different formats; they were in fact the complementary spirit. Leshan and Margenau defined principles, graphed results, reviewed scientific constructs; Pirsig's made a literary pilgrimage of the mind and spirit. One was the chariot of rationality; the other was the black steed of emotion. I had discovered "Phaedrus" – the conflicting spirit within me – one, the rational intellectual and one, the reader of books searching for freedom.

Not only my students but also two very different professors, Dr. Russell Dobson and Dr. Judith Lepushitz, introduced me to a whole range of literature and puzzling scientific discoveries. They forced me to ask a different style of question about myself, my teaching practices, and learning in general. I continued to read about quantum paradoxes and elegant fractal images, of uncertainty and complementarity. No longer did I define myself as a knowledgeable scholar. I became the participant observer and stepped into the world of high school students and into the middle of an advanced trigonometry class. I listened to students, and I learned—not much about mathematics, but a lot about learning and life.

And then,...I stopped. For five years my professional career took me out of the classroom and into the role of administrator. For multiple reasons, I packed my thesis into a file cabinet and put away my interest in quantum physics and bifurcations. This year I have begun again that arduous journey and returned to that "dog-eared" book of Zen and motorcycles--of learning and writing and thinking and studying.

For this return I thank my husband, Jesse, who quietly encouraged when I was most discouraged.

Now I write "Learning and the Mind Brain: Prigogine in the Classroom." The purpose of this epistemic inquiry is to discover the relationship of learning with discoveries in the physical sciences of chaos and complexity and in the biological sciences of evolution and neurophysiology. Perhaps, most importantly, I looked closely at how the student learner describes learning, and how we travel together on the mythical journey of learning. As a result, I examined my own personal pedagogy. As a special note, the quotations used at the beginning of each subsection are the results of years of my personally collecting quotes. Most of authors can be referenced directly in the selected bibliography; however, some of the authors are annotated only by brief notes of past readings.

Did I create a revolutionary theory? No, but I found new questions educators should ask about how children learn. I discovered students have much to offer if only I took the time to listen. I questioned my old teaching methodologies and found new dialogues. Hopefully through reading this epistemic inquiry, others can discover even more definitive answers that lead from the chariot of Phaedrus into the workings of the minds of children.

Every once upon a lifetime the web of ideas interconnect, and

the mind begins to jump in randomness

reaching with the depths of neuron tendrils to exclaim,

"I understand."

ACKNOWLEDGMENTS

Thank you, Dr. Russell Dodson, for forcing me to question my educational practices. Thank you, Dr. Judith Lepushitz, for saying the right things to me at the right time and for encouraging my writing style.

A very special thanks to my new committee members: Drs. Kathryn Castle, Natalie Adams, Martin Burlingame, Wen-song Hwu, and Pamela Bettis. Special recognition goes to my new thesis advisor, Dr. Adams and my chairperson, Dr. Castle. To you, Dr. Adams, your encouragement, phone calls and e-mails kept me working. I know you worked me into your filled schedule because you cared. Thank you for believing that the whole process was possible. To you, Dr. Castle, thank you for helping me and my cause. I have a deep respect and admiration for you.

Finally, thank you, Jesse, my husband, for always loving me, for always supporting me and for reminding me this degree has been a life-long quest.

TABLE OF CONTENTS

Chapter Page

Chapter Page

LIST OF FIGURES

Shophenauer...points out that when you reach an advanced age and look back over your lifetime, it can seem to have had a consistent order and plan, as though composed by some novelist. Events that when they occurred had seemed accidental and of little moment turn out to have been indispensable actors in the composition of a consistent plot. So who composed that plot? Schopenhauer suggests that just as your dreams are composed by an aspect of yourself of which your consciousness is unaware, so, too, your whole life is composed by the will within you. And just as people whom you will have met apparently by mere chance become leading agents in the structuring of your life, so, too, will you have served unknowingly as an agent, giving meaning to the lives of others. The whole thing gears together like one big symphony, with everything unconsciously structuring everything else....one great dream of a single dreamer in which all the dream characters dream, too,...Everything arises in mutual relation to everything else, so you can't blame anybody for anything. It is even as though there were a single intention behind it all, which always makes some kind of sense, though none of us knows what the sense might be, or has lived the life that he quite intended.

- Joseph Campbell, 1988, The Power of Myth

True education…is at once a fulfillment and a spur; always at the goal and never stopping to rest. It is a journey in the infinite, a participation in the movement of the universe, a living in the timelessness. Its purpose is not to enhance particular abilities; rather, it helps us to give meaning to our lives, to interpret the past, to be fearless and open toward the future.

- Hermann Hess, 1974, Reflections

Not Chaos-like, together crushed and bruised,

But, as the world harmoniously confused.

Where order in variety we see,

And where, though all things differ, all agree.

- Alexander Pope, 1733, Essay on Man

A. A violent order is disorder; and

B. A great disorder is an order.

These two things are one.

- Wallace Stevens, 1942, "Connoisseur of Chaos"

CHAPTER ONE

THE JOURNEY OF THE LEARNER

Introduction

> What is the stuff of the world?
> Of earth and trees and water and air?
> What makes stones sod and clouds soft?
> What makes the stars the way they are?
> What is the universe made of?
>
> These questions are as ancient as philosophy, universal as curiosity, and fundamental as language. They are asked by six-year-old children, by poets and physicists and astronomers with sophisticated instruments.
>
> ♦ Sandra Bradley, 1990, <u>The Quantum Universe</u>

In the video <u>The Quantum Universe</u> (Bradley, 1990), a young voice penetrated the observer's mind as he questioned what forces "bind and hold the universe." This video then juxtaposed scientific thought of quantum mechanics and chaos theory with ancient myths, the modern arts, literature and philosophy. Nature and humanity mirrored dynamic and creative processes through patterned and transforming interrelationships. What forces "bind and hold the universe"? The child looked at nature and asked the questions of what, how and why; the child constructed the learning process.

The construction of the learning process began with experience and questioning.

question":

> It's an unexpressed question most of the time, or perhaps always. Our very life is a quest, a questioning. And once in a while, for no particular reason, we glimpse the answer. But the answer is not yet spelled out. We just say, "This is it!" ....It is this kind of being able "to rest in it" from our restlessness with which we normally pursue life (p. 14).

Personal questioning then became a universal lifelong quest. Disquietude motivated the learner to continue the journey. The learner interacted with the environment, reflected the relationship with nature, and constructed an ever-changing world view. Steffe and Gale (1995) clarified the relationship of the learner to his or her world: "Knowledge is regarded as being constructed by the individual, such that the individual creates meaning <u>of</u> the world, rather than discovers meaning <u>from</u> the world" (p. xii).

This dynamic relationship, a process of "worldmaking," involved a formative purpose of "learning in the widest sense." (Cobb, 1977) The process of worldmaking and the journey of learning became one, forming domains of subjective experience. According to Bauersfield (1995), these domains of subjective experience could be understood as a holistic process forming rich mixtures of emphases and selection: "Human experiencing involves all senses, and the 'mental states in our brain' preserve this multidimensionality from our experience" (p. 152). This journey of learning continued throughout each person's lifetime in a discontinuous—but creative way—by objectifying nature through subjective thought.

In an attempt to understand the journey of the learner, Fritjof Capra, a physicist and well-known writer, exhorted the researcher to explore multiple avenues: "Science can never provide any complete and definitive understanding of reality" (Capra & Steindl-Rast, p. xv). Rather than looking for the "one" true theory of learning and discarding all others, I followed the suggestion of David Bohm, another quantum physicist who proposed that science followed art. He posed scientific truth, like artistic truth, was a matter of endless nuance, of "worlds in rotation" (as cited in Briggs & Peat, 1989, p. 200). As the learner interpreted the infinite nuances of subjective experience, he or she discovered multitude and often contradicting ways to see the world.

Because of the infinite nuances, I defined this study as an epistemic inquiry. I began first by recognizing the diverse ways of worldmaking. I advocated the qualitative methodology of grounded theory (Glasser & Strauss, 1967; Strauss & Corbin, 1990) and resources of multivocal literature (Ogawa & Malen, 1991) as viable qualitative research tools. Secondly, integration began in the multivocal literature of psychology, biology, and the neurosciences. Chaos and complexity science were examined closely. I then turned to the learner to describe the learning process. As I integrated their voices with the mutlivocal literature, I reminded all educators processes of learning were reciprocal sharing between and among students and teacher. Through the indepth interviews, students described the personal, yet paradoxically, the universal search for understanding. Finally, summary findings explained the emerging learning process to facilitate educators as they develop their own personal pedagogy.

Throughout this epistemic inquiry, new relationships and personal understandings have been created. The scientists, the psychologists, the students and I were intimately connected in the universal quest of worldmaking. I, the researcher, was also intricately bound in multilayered dimensions; for as I search for understanding, I, too, was the learner in process.

The Metaphoric Search

> Today there is a wide measure of agreement...that the stream of knowledge is heading towards a non-mechanical reality; the universe begins to look much more like a great thought than a great machine.
>
> ♦ James Jean, 1930, The Mysterious Machine

Throughout the ages, literature had used the metaphor of journey to represent the search for truth and understanding. For example, Ann Morrow Lindbergh (1975, 1955) looked subjectively at nature: "I began these pages for myself, in order to think out my own particular pattern of living, my own individual balance of life, work and human relationships"(p. 9). She picked up a channeled welk, a snail-like animal, and saw the pattern of her thoughts: "...you have set my mind on a journey, up an inwardly winding spiral staircase of thought" (p. 35). Intuitively, she discovered the convolutions of her mind in the complexities of nature. In this study, I explored the dynamics of students' learning within the framework of new discoveries of physical and biological sciences. To extend the limitations of traditional scientific discourse, I turned to the artistic metaphor.

Susan Drake (1991), an educator, chose the mythic metaphor to describe the universal journey of the learner. She framed the learner in the classic heroic proportions of Theseus to depict change and transformation. Drake then developed her own theory of learning or "planned ambiguity as pedagogy": "As I [understand] it, the learning journey [cannot] simply be added to an existing framework. This would require a transformation identity…a hero's odyssey…a recognition of [one's] own unrealized potential" (pp. 48-49).

In today's public school, students experienced unique transformational journeys of learning to define themselves. They often stumbled with the inadequacies of language to phrase universal questions about the natural world: "Like somethings, even in stuff…in real life or in planets out there, or [why] is the earth round? How do you know that?" (Student III). Another student related to an author's point of view and found himself: "Even just figuring out that you don't like one author's view, you learn a little about yourself. And that can help you relate to the world and other people and events" (Student I). Student IV posited a philosophical inquiry reflective of the centuries old search for understanding: "Whenever you have something that's unknown, and you don't know just by looking at it, you don't know anything yet and you are really curious. I mean what is the answer to be like? What is the purpose?…Questions like that go through your mind."

Famous scientists experienced similar conundrums. In the ancient Greek story, Archimedes struggled for days with the problem of determining the amount of gold in the king's crown. He stepped into his bath and then suddenly yelled, "Ah! Eureka!" He had juxtaposed different frames of references and achieved the solution to his problem. Similarly, Poincare, the famous French mathematician, experienced juxtapositions repeatedly, usually outside his work place. Poincare defined his pattern of scientific discovery to be "one of initial frustration, confusion, and mental chaos followed by unexpected insight… [with the] characteristic of brevity, suddenness and immediate certainty." (Briggs & Peat, 1989, p. 192). For example, he took a brief vacation from his work. While concentrating on boarding a omnibus, from out of "nowhere" he discovered the relationship of fuchsian functions with non-Euclidean geometry. Another famous scientist, Warren Heisenberg, formulated the uncertainty principle while taking a trip to an island to relieve some allergy problems. Out of context and juxtaposed with disparate concepts, suddenly brilliant ideas emerged.

The students—like these scientists—found partial answers and experienced the "Ah! Eureka": "Finally, I got it!...Did a little dance around the room and everything. It made me so excited and I went back to class....I got it, I got it! It took me so long! It makes me want to go on to something new and try to do it again and go back to the problems I didn't think I could get and then try them again. And it gives me just a little more energy!" (Student XV).

Each person was looking for meaning and creating his or her own pattern of reality. By using the complexities of the thinking processes, the students and the scientists began individual odysseys to understand the complexities of the universe. Gaining a greater awareness of the universe, they also gained a greater awareness of self; however, the feedback loop was reciprocal. As they gained greater understanding of self, they understood humanity was a part of the totality of the universe. In worldmaking, each person created the world. Objective and subjective thought became interwoven to provide multiple perspectives and dynamic interrelationships.

Can the journey of worldmaking be paradoxically universal and still be unique for each learner? How does each person learn? What is the relationship of scientific theory and the individual learner? How is learning defined?

The Paradox of Order and Disorder

> When a mystery is too overpowering, one dare not disobey. Absurd as it might seem to me, a thousand miles from any human habitation and in danger of death, I took out of my pocket a sheet of paper and my fountain pen, but then I remembered how my studies had been concentrated on geography, history, arithmetic and grammar, and I told the little chap (a little crossly, too) that I did not know how to draw. He answered me: "Draw me a sheep."
>
> ♦ Antoine de Saint-Exupéry, 1943, The Little Prince

Like the metaphor of the journey, a diversity of metaphors illustrated the tension between order and disorder or chaos. Mythical traditions often depicted "cosmic creativity" dependent upon the reciprocity of order and disorder (Campbell, 1990). Briggs and Peat (1989) began their definitive study of chaos science with a review of historical mythological references to chaos (pp. 19-24). In ancient Babylon, multiple gods symbolized the various faces of chaos in the creation myth; the various faces also implied order within the formlessness. In ancient Greece, Hesiod's Theogany (700's B.C.) connected chaos with creation, "First of all things was chaos; and next broad-bosomed Earth."

The Chinese extended the myth of chaos and order with the principle of order, yin, as dragons emerging from the disorder of chaos, yang, implying a paradoxical interrelationship, "...at odds, yet are an integral part of each other." Within the Judeo-Christian religions, the creation of the universe began "without form and void" until God intervened: "When God began creating the heavens and the earth, the earth was at first a shapeless, chaotic mass, with the Spirit of God brooding over the dark vapors" (The Way, Genesis 1:1-2).

According to René Girard, a noted psychologist and anthropologist, historically Western cultures attempted to improve mythology by suppressing disorder and emphasizing order (Briggs & Peat, p. 21). Even the word "dis-order" emphasized the precedence of order. Influenced by Aristotle's focus on order, the oracles of Delphi and other mythological traditions were gradually replaced in Western culture by the scientific approach and hierarchical order of the Middle Ages. Finally in the eighteenth century epitomized by Isaac Newton and René Descartes, chaos and creation were replaced by mathematical formulas.

Newton created a mechanical and static worldview, described by the metaphor of a clock, based primarily on the dual variables of motion and velocity. Pierre Simon de Laplace, a French mathematician, epitomized the certitude of Newton's clocklike world. He declared mathematical formulas would soon explain everything with absolute certainty and predictability and unequivocally stated: "Given for one instant an intelligence which could comprehend all the forces by which nature is animated and the respective positions of the beings which compose it…nothing would be uncertain, and the future as the past would be present to its eyes (as cited in Casti, 1994, p. 87).

The first significant challenge to Newton's clocklike world was science's inability to create a perpetual motion machine. No matter what method scientists used for a perpetual machine, some unrecoverable energy left the system in a chaotic fashion. This "progressive disorganization of useful energy" formed the basis of the significant idea of entropy in the science of thermodynamics (Briggs & Peat, p. 22). Ludwig Boltzmann first attempted to fit entropy into the Newtonian world. He postulated the end of the world as a great homogeneity, "a lukewarm molecular cosmos: meaningless, sexless, formless...passive chaos of thermal entropy is simply an expression of the Newtonian order" (Briggs & Peat, p. 22).

But then Boltzmann began looking at chance and probability in the physical world. Later in the biological world, Charles Darwin and Alfred Wallace explored possibilities of random chance and mutations. Darwin's theory of evolution credited random chance with creating new forms and variations within species. In the mathematical world, Henri Poincare exposed the limitation of the Newtonian linear differential equations by interjecting multiple relationships. Newton's clocklike world of precision collapsed with nonlinearity formulas. In a nonlinear world, exact prediction became both practically and theoretically impossible.

Einstein's general theory of relativity incorporated these nonlinear equations. His fourth dimension of space-time reconceptualized the boundaries of the micro- and macro-universes. In 1927, Warren Heisenberg's uncertainty principle exposed limits to the scientific questions; in 1931 Kurt Godel challenged the mathematical world of formal axiomatic structure. Objectivity and subjectivity were redefined.

Chaos, catastrophic and complexity theories emerged to challenge old philosophical constructs. Brian Arthur, a Los Alamos physicist, summarized these findings:

> People realized that logic and philosophy are messy, that language is messy, that chemical kinetics is messy, that physics is messy, ...And it's not that this is a mess created by the dirt that's on the microscope glass. It's that this mess is inherent in the systems themselves. You can't capture any of them and confine them to a neat box of logic....The result ...has been the revolution in complexity (Waldrop, 1992, p. 329).

As discovered nature resisted the confines of the neat box of quantitative methodology, David Bohm, Einstein, and others turned to koans, or scientific thought questions, to understand the paradoxes and messy systems now apparent in relativity and quantum mechanics. The objective merged with the subjective.

Emergent Relationships

> Any path is only a path, and there is no affront, to oneself or to others, in dropping it if that is what your heart tells you...Look at every path closely and deliberately. Try it as many times as you think necessary. Then ask yourself, and yourself alone, one question...Does this path have a heart?
>
> If it does, the path is good; if it doesn't, it is of no use.
>
> ♦ Carlos Castaneda, 1968, The Teachings of Don Juan

In spite of the paradoxical discoveries of the twentieth century, people still held firmly to the beliefs of Newton's clocklike deterministic universe. K. R. Popper in The Open Universe: An Argument for Indeterminism (1992) dishearteningly explained how this belief system prohibited not only exploration in the physical world but also understanding in the subjective world: "I regard Laplacian determinism—confirmed as it may seem to be by the *prima facie* deterministic theories of physics, and by their marvelous success—as the most solid and serious obstacle to our understanding and justifying the nature of human freedom, creativity and responsibility" (p. xix).

Einstein still questioned quantum physics by his famous dictum, "God doesn't play dice." Discoveries in DNA and RNA overshadowed discoveries in the holistic approaches of organismic biology. Behaviorists pushed aside Gestalt and humanistic psychology.

Fritjof Capra's writings (1982, 1983, 1996; Capra & Steindl-Rast, 1991) attempted to counter this Laplacian determinism as he discussed the evolution of thought, understanding, and metaphoric language of the last twenty-five years. His writings had strongly influenced my personal journey of learning. He detailed discoveries in physics, biology, and psychology to highlight the patterns and interrelationships of the world. He saw the objective and the subjective as one.

According to Capra (1996), Western scientists and philosophers repeatedly used the metaphor of knowledge as a building, the "edifice of science must be built on firm foundations" (p. 38). To further our understanding, Capra compared Descartes and Heisenberg:

> [Descartes]: In so far as [the sciences] borrow their principles from philosophy, I considered that nothing solid could be built on such shifting foundations.
>
> [Heisenberg]: The violent reaction to the recent development of modern physics can only be understood when one realizes that here the foundations of physics have started moving; and that this motion has caused the feeling that the ground would be cut from under science (René Descartes, 1637, Discourse on Method and Warren Heisenberg, 1971, Physics and Beyond as cited in Capra, pp. 38-39).

Descartes strongly believed nature had a fundamental division of two separate worlds, that of the mind (res cogitans) and that of matter (res extensa). The objective world was independent of the human observer and the process of knowledge. However, quantum physics radically changed the dichotomy of the objective world and the observer as well as changing epistemology. According to quantum theories, not only did the observer affect his observations; knowledge itself could never be complete.

The understanding of Heisenberg's uncertainty principle was essential, according to Capra (1983), because its precise mathematical form ironically described the limitations and therefore the imprecisions of the classical concepts (p. 159). Within this mathematical formula, nature was not revealed by "isolated basic building blocks, but rather [appeared] as a complicated web of relations between the various parts of a unified whole" (Capra, 1982, p. 81). In 1958, Heisenberg described the interconnected world: "The world thus appears as a complicated tissue of events, in which connections of different kinds alternated or overlap or combine and thereby determine the texture of the whole" (<u>Physics and Philosophy</u> as cited in Capra, 1982, p. 81).

This shift from the Cartesian paradigm evolved into the metaphor of knowledge as network. This network view crystallized in Ludwig von Bertalanffy's theoretical framework of general systems theory. Capra (1996) explained this shift: "Thus systems thinking [involved] a shift from objective to 'epistemic' science, to a framework in which epistemology—'the method of questioning'—[became] an integral part of scientific theories" (p. 40).

Journeys to the Systems View

> This we know.
> All things are connected
> like the blood which unites one family....
> Whatever befalls the earth,
> befalls the sons and daughters of the earth.
>
> ♦ Ted Perry (inspired by Chief Seattle)

At the early age of fourteen, Doyne Farmer, a founder of chaos theory, questioned the complicated principle of entropy after reading Isaac Asimov's science fiction short story, "The Final Question." In this story, humans asked a supercomputer how to reverse the second law of thermodynamics. Finally after life disappeared, the computer solved the problem and declared, "Let there be light." A new low-entropy universe was created.

Farmer recounted his questioning: "If entropy is always increasing…and if atomic-scale randomness and disorder are inexorable, then why is the universe still able to bring forth stars and planets and clouds and trees? Why is matter constantly becoming more and more organized on a large scale, at the same time that it is becoming more and more disorganized on a small scale? Why hasn't everything in the universe long since dissolved into a formless miasma?" (Waldrop, 1992, p. 286).

Boatsmann's "lukewarm meaningless cosmos" and Farmer's "formless miasma" were examples of metaphors describing the yet unexplained. Ultimately, Carnot was credited with a definitive formalization of entropy in his second law of thermodynamics. According to Carnot, isolated closed physical systems moved from order towards the irreversible direction of ever-increasing disorder. In contrast to this explanation of the physical world, Darwin and Wallace, and later evolutionary biologists throughout the twentieth century, felt the living universe was moving from disorder to ever-increasing higher complexities of order. The ancient mythic idea of creativity and reciprocity between order and disorder was reappearing.

Although not able to resolve completely the conflicts of the theories of Darwin, Wallace, and Carnot, Ludwig von Bertalanffy distinguished the differences between the closed physical systems of the second law and the open systems of living organisms. As open systems, living organisms exhibited a continual flux and interchange of energy and matter from their environment rather than constantly losing energy. Bertalanffy selected a German term, fliessgleichgewicht (flowing balance), to describe this dynamic state of balance. Through self-organization, living systems functioned "far from equilibrium...characterized by continual flow and change" (Capra, 1996, p. 48).

Bertalanffy (1968) further postulated these general systemic concepts apply to a broad range of phenomena in different fields of study: "The parallelism of general conceptions or even special laws in different fields...is a consequence of the fact that these are concerned with 'systems,' and that certain general principles apply to systems irrespective of their nature" (p. 84).

General systems theory gave way to the new field of cybernetics. Like Bertalanffy, the brilliant mathematician, Norbert Wiener, drew from disparate fields of study which included engineering, neurobiology, anthropology and the humanities. Cybernetics' importance to this epistemic inquiry was multifold. Wiener, and later Gregory Bateson, focused on holistic explanations and self-perpetuating patterns. Out of their work, new ideas and new language appeared—homeostasis, positive/negative feedback, information theory, and communication theory. Nonetheless, according to Capra (1996), Bateson's single most important contribution was the formulation of the "nature of mind as a systems phenomena [thus becoming] the first successful attempt in science to overcome the Cartesian division of mind and body" (p. 55).

The contemporary science of cognition—looking at a unified conception of brain and mind—could be traced directly from Bateson and the field of cybernetics. However, until the late 1980's, the metaphor of the computer characterized the research. Information processing signified learning. Artificial intelligence defined the process of knowing as "manipulation of symbols based on a set of rules" (Capra, 1996, p. 66). In forecasting the future of artificial intelligence, Herbert Simon and Allen Newell exhorted: "There are now in the world machines that think, that learn and that create. Moreover, their ability to do these things is going to increase rapidly until—in the visible future—the range of problems they can handle will be coextensive with the range to which the human mind has been applied" (J. Weizenbaum (1976), Computer Power and the Human Reason, New York: Freeman as cited in Capra, p. 66). The advances of technology sent psychology back to Newton's clocklike universe.

Like the metaphor of the clock, the metaphor of the computer appeared to solidify thinking. The language of information processing reinforced the idea of man as machines. But recent developments in the cognitive sciences have proven that the human nervous system and human intelligence were radically different from "artificial intelligence" and the computer image (Capra, 1996; Edelman, 1992; Penrose et. al., 1997). Persons did not process information as discrete elements; rather they interacted with the environment which, in turn, continually modulated the structure of the human nervous system. Human brains operated not on the basis of a set of rules but rather on the basis of a network of massive connectivity.

These revolutionary ideas of learning were predicated on constructs of self-organization of dissipative structures (Prigogine & Stengers, 1984; Prigogine, 1996); the theories of autopoiesis (Varela, Thompson & Rosch, 1991; Maturana, Mpodozis & Letelier, 1995; Whitaker, 1998); and evolutionary biological organization (Edelman, 1992). Ilya Prigogine, a Nobel Prize laureate, introduced the key idea of dissipative structures—order and organization arising spontaneously out of disorder and chaos through self-organization (Prigogine & Stengers, 1984; Prigogine, 1997). Maturana's early work in the neurosciences questioned information theories as explanations of cognition. He and Varela then jointly created the theory of autopoiesis which later included epistemology, communication and social systems. Another neuroscientist and also a Nobel Prize winner, Gerald Edelman (1992) suggested a particular kind of evolutionary biological organization. This organization gave rise to mental processes, through an "enormously intricate brain systems of many different levels of organization" including molecular, cellular, organismic, and transorganismic (p. 7).

Radically different from the metaphor of a computer, these authors concurred the human mind worked with ideas patterned through experience, not with information perceived in an external reality. The mind was a process rather than a physical entity with language as the integrative component. The current metaphor for learning emerged seeking definition.

The Physicist, the Psychologist, and the Educator

> For, after all, is science concerned solely with predictions and experimental verification and with the accumulation of new knowledge? Science, I would suggest, is really about understanding ourselves, the universe, and our position in it. Science, according to such view, is not fixed but fluid, and its methods, approaches, and techniques must be always ready to change and to respond in creative ways to meet new demands and new situations.
>
> ♦ F. David Peat, 1987, Synchronicity

The field of education perhaps had been even more reluctant than fields of science to give up the Newtonian search of a one definitive answer for pedagogical concerns.

Although the dynamic interrelationships of the learner, the classroom, and the individual's world might appear obvious in informal discussions, educational research has traditionally favored the laboratory and the quantitative statistical method. Pedagogy had continued to utilize the lecture and rote memory. Educational training and practices had dismissed the significant changes in methodologies in the physical sciences, as well as reduced the scientific discoveries applicable to the complexities of the human learning processes.

Mirroring the Laplacian mindset at the turn of this century, Edward L. Thorndike looked for the "control-oriented conception of educational research" to discover the laws of learning:

> A complete science of psychology would tell every fact about everyone's intellect and character and behavior, would tell the cause of every change in human nature, would tell the result which every educational force—every act of every person that changed any other or the agent himself—would have....In proportion as we get such a science we shall become masters of our own souls as we are now masters of heat and light (Thorndike, 1910, "The Contribution of Psychology in Education," Journal of Educational Psychology as cited in Eisner, 1985, pp. 8-9).

Although John Dewey also believed in the scientific method, his theories and practices diverged from controlling philosophy of the behaviorists. Dewey recognized the dynamics of the learner and the differences between the laboratory and the classroom (Eisner, p. 9). However, the control-oriented psychology and pedagogy maintained dominance throughout the twentieth century; and I maintained, current classroom practices still reflected the behaviorist ideology. But like classical scientific thought, many traditional educational premises and practices were no longer viable for the twenty-first century. Bertalanffy's (1952) description of evolving science was applicable to this discussion: "The evolution of science is not a movement in an intellectual vacuum; rather it is both an expression and a driving force of the historical process" (p. 52).

This historical process was reflected in the term "paradigm." Thomas Kuhn (1970) popularized the word "paradigm" in his often-quoted book, The Structure of Scientific Revolution. The term itself, paradigm, had been misapplied and misquoted often in educational journals; however, this term was critical to this inquiry. A scientific paradigm was more than individual scientific discoveries or even more than "doing science"; the evolution of science mirrored and drove our cultural forces into historical epochs. Capra (1991) used the more applicable term of social paradigm:

> A social paradigm…is a constellation of concepts, values, perceptions, and practices, shared by a community that forms a particular vision of reality that is the basis of the way the community organizes itself. It's necessary for a paradigm to be shared by a community. A single person can have a worldview, but a paradigm is shared by a community (p. 34).

When someone attempted to articulate a different viewpoint, methodology also needed to change. Kuhn (1962) insisted the needed type of experiments resembled "exploration." He asserted exploratory experiments were necessary when the researcher was looking at new areas of interest. The need was even more pronounced during periods when science "deals more with the qualitative than with the quantitative aspects of nature's regularity" (p. 29).

Methodology Rationale

> Like any set of skills, the learning involves hard work, persistence, and some, not always entirely pleasurable experiences.
>
> ♦ A. L. Strauss, 1987, Qualitative Analysis for Social Scientists

The focus of this study compared students' definitions of learning within the institution of learning—the public school—with recent theories of chaos and complexity sciences, neuroscientific discoveries, and educational philosophies. Through this comparison procedure, constructs beginning in grounded theory framed students' definitions of learning with this review of literature encompassing science, philosophy, and pedagogy.

Glaser and Strauss (1967) and Strauss and Corbin (1990) provided a challenge to quantitative approaches of educational research. Their focus of grounded theory was the integration of methodology with issues of human behavior. Perhaps a definition of grounded theory would clarify this approach:

> A grounded theory is one that is inductively derived from the study of the phenomenon it represents. That is, it is discovered, developed, and provisionally verified through systematic data collection and analysis of data pertaining to that phenomenon. Therefore, data collection, analysis, and theory stand in reciprocal relationship with each other. One does not begin with a theory, then prove it. Rather, one begins with an area of study and what is relevant to that area is allowed to emerge (Qualitative Research, 1998, p. 1).

I derived my data collection from (1) twenty-six hours of participant observation within a high school advanced mathematics classroom; (2) fifteen indepth interviews of students who were enrolled in this class; and (3) a multivocal review of books and journal articles covering current theories and discoveries of educational, physical, biological, and neuroscientific research. As an inductive study, the underlying question was "How do we learn?"

Planned Ambiguity as Pedagogy

> Originally you were clay. From being mineral, you became vegetable. From vegetable, you became animal, and from animal, man. During these periods man did not know where he was going, but he was being taken on a long journey nonetheless. And you have to go through a hundred different worlds yet. There are a thousand forms of mind.
>
> ◆ Jalluludin Rumi (source unknown)

This research project mirrored discovering the meaning of learning on multilevels of experience. Susan Drake (1991) suggested the premise of the journey of the learner as a metaphor for personal transformation. She discussed her own theory of "planned ambiguity as pedagogy" within the framework of the mythic hero Theseus (p. 48). Drake used Ken Wilbur's definition of a hero's odyssey as "a mythic metaphor for coming to terms with [one's] own unrealized potentials" (Wilbur, 1990, "Two Patterns of Transcendence: A Reply to Washburn," Journal of Humanistic Psychology, 30, p. 43 as cited in Drake, p. 49). Her term, "planned ambiguity as pedagogy" seemed to fit with my search. My own studies had also led me to myths and to Joseph Campbell's (1974, 1990) explanation of the cross-cultural monomyth, the "journey of the hero."

Again to compliment Drake and to complement my study, the mythic journey of the hero learner continued. Chapter titles referred to the story of the Greek hero, Theseus. Drake and I used Theseus to facilitate understanding of the territory one travels when "negotiating change or transformation" (p. 50). I had used interludes between and within the chapters to provide insight into my personal journey of learning as well as encouraging the reader to search for his or her own personal definition of learning. The remainder of this epistemic study was the explication of the journey towards understanding the complexities of the dynamic learning process delineated as follows:

Chapter 2. Adrianne's String: Epistemic Inquiry as an Alternative Approach

The question of the importance of educational theory was first addressed followed by the justification of the term "epistemic inquiry." Qualitative methodologies of participant observation, indepth interviews, and the multivocal literature were detailed. The chronology of the study and the data collection formed a guide through the maze of scientific discoveries and theoretical constructs considered.

Chapter 3. The Journeys of Theseus: Contemporary Complexity and the Mind Brain

The impact of chaos theory, complexity theory, dissipating structures, and autopoiesis was analyzed. Studies in the neurosciences and Gerald Edelman's metaphor of the brain as a jungle were introduced. Within the multivocal literature were woven the voices of the students to emphasize and substantiate the presented theories of how the individual learner experienced the world. New metaphoric language and homologies were presented as well as the introduction of the term mind brain. The basic premise of biological organization giving rise to mental processes of learning was further detailed.

Chapter 4. The Modern Hero: Prigogine in the Classroom

A definition of learning finally was presented for the reader's perusal. The emergent ideas of the dynamics of mind brain learning process were summarized. Limitations and improvements of the current study as well as educational applications and further research needs were included.

INTERLUDE 1

The Empty Toilet Paper Roll, the Boa Constrictor, and the Hat

> A finely tempered nature longs to escape from his noisy cramped surroundings into the silence of the high mountains where the eye ranges freely through the still pure air and fondly traces out the restful contours apparently built for eternity.
>
> ♦ Albert Einstein (source unknown)

As I moved from introduction to the methodological explanations, I was reminded of an example presented in a workshop using cameras in the classroom. Mark Zimmerman, Director of Development of Polaroid Education Program, suggested using an empty toilet paper roll and a four-foot string to view the world capturing it in time and space through photography. Suddenly an homology emerged! Was this not what I had been doing in my mechanistic framework to understand my world. In the classroom, sometimes the string was cut even shorter—only seeing and using the adopted textbook and the teacher's guide. I never questioned; I never looked further.

Researchers and teachers, the observers, had built a narrow perception—a discardable toilet paper roll—in search to find the secrets of the universe. They had limited visions in time and space by placing arbitrary dimensions—homologous to a four-foot string. And yet, many persons were reluctant to throw away the useless guides because, strangely, the guides and methods had worked in the past.

Empiricism came from the Greek empeirikos—relying on experience alone. One definition of the word, according to Webster (1997) was "quackery, or charlatanry." Although by its nature, empiricism was conservative, researchers could not negate its successes; therefore, they were reluctant to admit its weaknesses—and their own. But in Buddhism, thinking was designated as the sixth sense, an essential part of experience and perception. The feel for data—that sixth sense of intuition—was finally recognized, albeit reluctantly, as part of the alternative paradigm.

Perhaps that sixth sense could be described in a different way. Susan Oyama (1985) described how an issue in child development theory reminded her of the drawing of the boa in de Saint-Exupery's (1943) Little Prince. With that reminder, I re-examined my own copy of de Saint-Exupery's book and puzzled over the strange picture looking like a hat to everyone but the small child narrator (See Figure 1 for a copy of the illustrations). This six-year-old described discovering the boa's story from True Stories from Nature, "I pondered deeply, then, over the adventures of the jungle" (p. 7).

Let me continue with the first two pages of this wonderful myth of the modern world. True Stories... described the facts: boa constrictors swallowed their prey whole without chewing. After that boas were not able to move and sleep through six months they needed for digestion. After pondering deeply, the young child drew the picture of the boa swallowing an elephant and asked the grown-ups if the drawing frightened them. But to the grown-ups, the drawing was only a hat. The young child tried again with Drawing Number Two, but neither the boa nor the elephant did the grown-up see. The grown-ups discouraged the child; and the child abandoned his drawings to devote himself to "geography, history, arithmetic and grammar" (p. 8). Leaving what might had been a "magnificent career as a painter," the child reasoned it was simply too tiresome "always and forever explaining" to grown-up who could not understand themselves (p. 8).

The child became an airplane pilot and lived (quite like the traveler in Zen and the Art of Motorcycle Maintenance) "without anyone [he could] really talk to," until an accident in the Sahara. The next day he awoke by an "odd little voice" who said, "If you please—draw me a sheep!" (p. 9). The mechanistic and the artistic were united with a strange attractor.

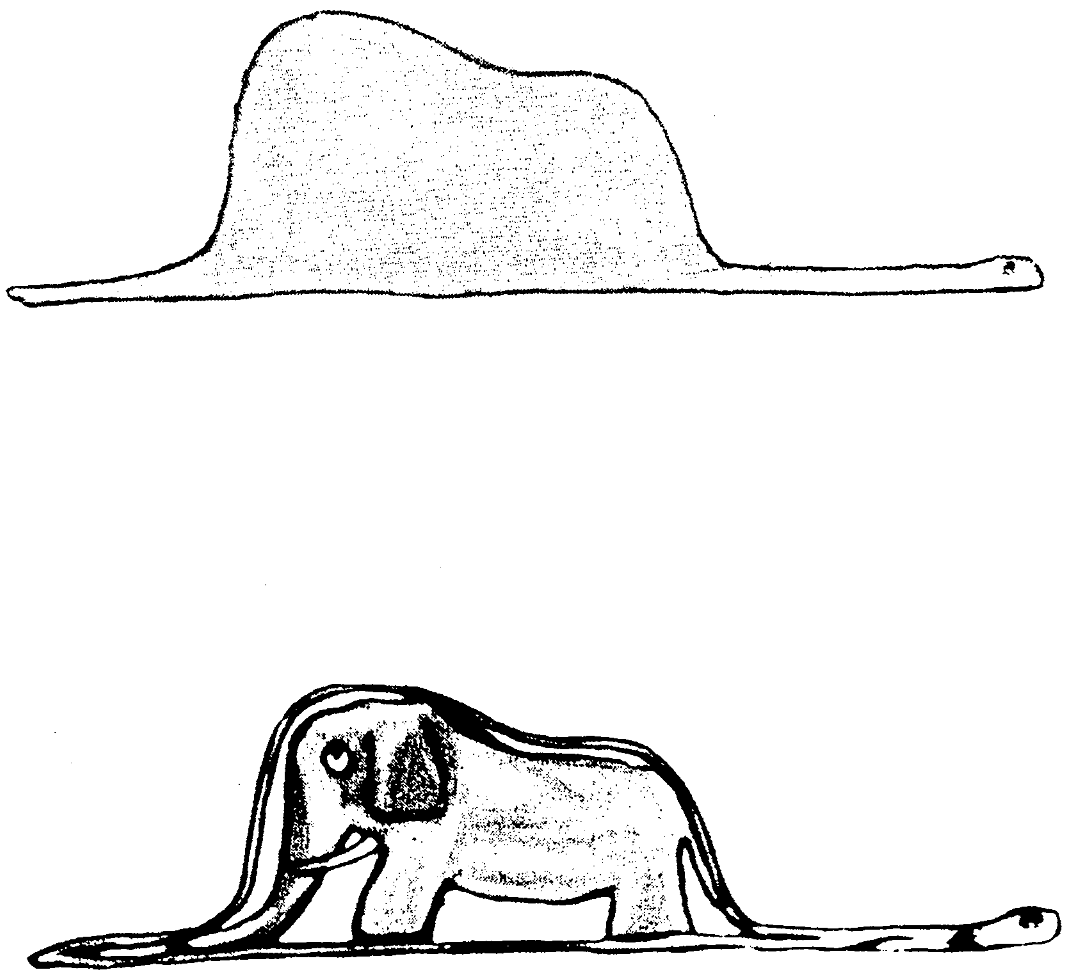


Figure 1

(Taken from Antoine de Saint-Exupéry (1943, 1972), The Little Prince, pp 7-8)

CHAPTER 2

ADRIANNE'S STRING: EPISTEMIC INQUIRY AS AN ALTERNATIVE APPROACH

Postsuppositions

> The mere formulation of a problem is far more often essential than its solution, which may be merely a matter of mathematical or experimental skill. To raise new questions, new possibilities, to regard old problems from a new angle requires creative imagination and marks real advances in science.
>
> ♦ Robert Olson, 1986, The Art of Creative Thinking

The originator of systems theory, Ludwig van Bertalanffy (1952) opened his book, Problems of Life, citing Arnold Schopenhauer, a nineteenth-century German philosopher: "Thus the task is not so much to see what no one has seen yet; but to think what no[one] has thought yet, about that [which] everyone sees" (p. 1). The etymology of the word theory literally meant to see. Curriculum theorizing must think what no one had thought by uniting diverse disciplines and multiplistic questioning. Through this union of disciplines and questioning, curriculum theorizing might then focus on the individual learner and the complex dynamics of the learning process.

However, Gary Thomas (1997) had made a controversial argument against using theory in any type of educational inquiry. He contended theory-making had been historically central to educational research; however, this "allure is puzzling" because of "theory's fragility, not its utility" (p. 75). His primary argument was with the multiplicity of meanings the field had attached to the word theory, ultimately reducing the meaning in actual practice to denote or imply, intellectual endeavor. In one succinct paragraph, Thomas negated the purpose of this writing. He lambasted theory—including educational theory, chaos theory, grounded theory, and personal theory—because he felt theory in general circumscribed modes of thinking about educational problems and actually inhibited creativity among its researchers and its practitioners:

> This is confusing for students of education, for education abuts a range of different kinds of theory: learning theory, attribution theory, Freudian theory, Rawl's theory of justice, critical theory, or Marxist theory to name a few. Even chaos theory is taken by Le Compte...to be a valid source from which to draw. Sociologists such as Glaser and Strauss (1967), who have questioned the traditional development of theory and its uses, have nonetheless shown a loyalty to the notion of theory, and have attempted to develop grounded theory. More recently, students of education have been encouraged to develop their own personal or practical theories...(p. 77).

In spite of his vitriol attack, Thomas, in my opinion, had defined my methodology and given credence for its use:

> Grounded theory (Glaser and Strauss, 1967), which does not find a neat fit...represents a distinguished inductivist position stretching back to John Stuart Mill and beyond. The central difference between grounded theory and other kinds of intellectual endeavor labeled theory is the temporal

> placing of the intellectual organization; in most theorizing one might say that presupposition exists, while what occurs in grounded theory might be called "postsupposition" and an iterative visiting of the data to refine the theory (p. 79).

I used the postsupposition approach and a constant revisiting of the data. To begin this discussion of methodology, first I referenced some of Thomas' important conclusions that not only support my methodology but also support my findings on how we learn:

> When breakthroughs in thinking occur, they almost always occur despite theory rather than because of theory. Progress in things occurs via "punctuated equilibrium" following individuals' energy, curiosity, and creativity....Successes appear to arise more often from accident—from the happy process of noticing (Kohler's apes' "Ah ha!"...)—and the unusual conjoining of ideas (sometimes outlandish ideas) than from the employment of theory. Looking at advances in knowledge from Archimedes's "Eureka!" to Einstein's thought experiments, it is probable that the vast majority of successes arise from "Ah ha!" experiences rather than from theory (pp. 99-100).

In contrast to Thomas, Elliot Eisner saw the multiplicities of theories and new scientific advancements as advantageous to education. In his critique of the field of curriculum studies, Eisner (1985) provided a broad directive: "For what I believe the study of education needs is not a new orthodoxy but rather a variety of assumptions...that will help us appreciate the richness of educational practice, that will be useful for revealing the subtleties of its consequences for all to see" (p. 23). Following Eisner's directive but realizing the multiplicities of the term "theory," I suggested, instead, the term "epistemic inquiry."

To explain further the term "epistemic inquiry," first I referenced Edmund Short's (1991) Forms of Curriculum Inquiry. In his introduction, he emphasized curriculum research formed both the substantive and procedural guidelines for governing educational programs; however, it was not the same as making practical curricular choices. "Curriculum research involves seeking and justifying the knowledge that is relevant to making [practical curricular] choices. It is an enterprise that involves undertaking formal inquiry to generate relevant knowledge" (p. 1). Short also preferred the term "inquiry" rather than "research" (p. 2) and presented a convincing argument that "multiple forms of inquiry" must be articulated "if curriculum questions are to be adequately addressed" (p. ix-x). He defined inquiry as "an intellectual activity in which we seek to find out something not yet known or clearly understood. Inquiry is prompted by the need to have reliable answers to certain perplexing questions" (p. 3).

However, inquiry was used in the sense of scholarly inquiry, quite different from the informal inquiries of everyday activities. Scholarly inquiry involved "painstaking and disciplined thought processes whereby answers to researchable questions can be established and verified with confidence" (p. 3). This mutual problem must be stated in language that facilitated understanding and provided a requisite value for curriculum action.

Richard Grove and Short included theoretical inquiry as one of many legitimate forms of curriculum and provided Ralph Tyler (1949), James MacDonald (1986), and John

Goodlad (1979) and others as exemplars (in Short, 1991, pp. 211-224). Although stating little had been written on how to do theoretical inquiry in curriculum, it must be "an interdisciplinary, creative and conjunctive enterprise" (p. 218). Grove and Short emphasized the importance of interdisciplinary contexts including the empirical, philosophical, and artistic dimensions.

In outlining theoretical inquiry, these two authors insisted on a wide experience or immersion in curriculum realities with processes and phenomena relevant to curriculum before beginning a framework of theory. These realities involved empirical, philosophical and artistic dimensions to determine fundamental judgments and perspectives. They posited three guidelines for conducting the theoretical inquiry: (1) Determine the scope and boundaries of the conceptualization of the curricular phenomenon or process. (2) Determine key elements and relationships phenomenologically. (3) Finally, critique and evaluate conceptual scheme assessing validity and efficacy (pp. 218-220).

Although I purposefully chose the word inquiry rather than theory, I based the choice on the premise that the theoretical process was the most powerful tool to understand and ultimately to change practice. Following these guidelines of theoretical inquiry for curriculum action as well as countering Thomas' argument, I also added the word epistemic. I wanted to focus on the creation of a personal epistemology, or act of knowing, in this qualitative inquiry (e.g., see von Glasersfeld, 1995).

According to Fritjof Capra (1991), researchers must shift from the objective science of the past to include the act of knowing or what Capra calls "epistemic science" (Capra & Steindl-Rast, pp. 123-133). The understanding of the process of knowing must be explicitly included in the descriptions of natural phenomena. Although there were no agreements on the appropriate epistemology, he felt strongly that epistemology must have an integral part in every scientific theory. He also felt constructivism was on the forefront as the appropriate epistemology:

> I think the people who are on the forefront of this research tend to say that a school known as "constructivism" is the appropriate epistemology. It says that what we observe is not a world that exists objectively and is then represented but is rather a world that is created in the process of knowing. As Maturana and Varela say: "The world is brought forth in the process of knowing" (Capra & Steindl-Rast, 1991, pp. 123-124).

In summary, the term "epistemic inquiry of curriculum" was most appropriate. I began my study using grounded theory constructs. I maintained the inductive process throughout the research, but used grounded theory coding only initially with the indepth interviews of the students. The interviews led me to the science of chaos as an alternative to current practices of behaviorism. When the data emerged that chaos theory was not the answer to my question of how we learn, but rather only a part of the learning process, I turned my inquiry more towards the interdisciplinary reviews of literature for further explanation. In contrast to the world of Newton and Descartes, in the new paradigm of thinking, "all concepts theories and findings are limited and approximate" (Capra & Steindl-Rast, 1991, p. xiv-xv). Rather than exact truth, I, like all others, deal with limited and approximate descriptions of reality.

Patterns and Homologies

I will put Chaos into fourteen lines
And keep him there; and let him thence escape
If he be lucky; let him twist, and ape
Flood, fire, and demon—his adroit designs
Will strain to nothing in the strict confines
Of this sweet order, where, in pious rape,
I held his essence and amorphous shape,
Till he with Order mingles and combines.
Past are the hours, the years of our duress,
His arrogance, our awful servitude:
I have him. He is nothing more nor less
Than something simple not yet understood;
I shall not even force him to confess;
Or answer. I will only make him good.

- Edna St. Vincent Millay, 1954, Mine the Harvest

In his book, Theories of Everything: The Quest for Ultimate Explanation, John Barrow (1991) explored myths, theology, physics, metaphysics, mathematics, and philosophy as he outlined the search for a unified and complete explanation of the universe. The relevance of Barrow's argument for this inquiry was embedded in his discussion of transformation of patterns as the "heart of scientific process" (p. 14). I extended his concept of pattern to form a broader context of language and metaphor. In selecting metaphorical language for science, Bertalanffy (1952) suggested the term homology. He believed it was especially important in multidisciplinary contexts not to extend and not to manipulate terminology. The term analogy implied superficial similarities rather than applications of laws. In contrast, a homology resulted from "general system characters…[and] structurally similar principles…in different fields, and so gave rise to a parallel evolution in different sciences" (p. 200). Homologies would be used in this epistemic inquiry to represent transformations of data from the interdisciplinary fields of chaos, complexity, neurosciences, and curriculum.

Philosophical Framework and Research Sensitivity

> An artist, in comparison with his fellows, is one who is not only especially gifted in the powers of execution but in the unusual sensitivity to the qualities of things. This sensitivity also directs his doings and his makings.
>
> ♦ John Dewey, 1934, Art as Experience

The philosophical framework of phenomenology intrinsic to the nature of learning also provided a braiding of the nature of the study and methodology. Phenomenology was a form of interpretive inquiry that "focuses on human perceptions, particularly on the aesthetic qualities of human experience" (Willis in Short, 1991, p. 173). Stressing the interpretive inner-world, according to Willis, this interpretation included "intuitive scanning of the inquirer's own primary consciousness, empirical scanning of evidence of the primary consciousness of others, and use of some means or medium...to render metaphorically what the inquirer has perceived...what they do or do not have in common" (p. 175). As an interpretive inquiry, Willis believed phenomenology came the closest to artistic inquiry; as individuals self-consciously reflected on alternative meanings and actions to determine what was most important or primary. This autonomous reflection then resulted in new understandings to both the external world action and the internal life-world.

Janesick (1982) extended phenomenology also to understand both the thought and action of the individual. To ask a student how he or she learned was to ask how situations, actions and individual life-worlds were defined. Critical to phenomenology and grounded theory, and I believed to this inductive inquiry as well, was also theoretical sensitivity, a personal awareness of the researcher. Strauss and Corbin (1990) defined this type of theoretical sensitivity:

> Theoretical sensitivity refers to the attribute of having insight, the ability to give meaning to data, the capacity to understand, and capability to separate the pertinent from that which isn't. All this is done in conceptual rather than concrete terms...that allows one to develop a theory that is grounded, conceptually dense, and well integrated (p. 42).

An integrated inquiry of curriculum came from a variety of sources, specifically literature, professional experience and personal experience. The literature source included multivocal fields of biological and physical sciences, neuroscience and education. Professional and personal experiences involved not only my educational career and background, but also my personal role as a life-long learner. The professional and personal experiential sources, however, had two limitations that needed to be noted: (1) a blocking from seeing the routine or obvious, and (2) a projecting of personal experiences to others. Descriptions could never objective, independent of the human observer and the process of knowing.

Chronology of the Research

> And just as people who you will have met apparently by mere chance became leading agents in the structuring of your life, so, too, will you have served unknowingly as an agent, giving meaning to the lives of others. The whole thing gears together like one big symphony, with everything

unconsciously structuring everything else....one great dream of a single dream in which all the dream characters dream too.

♦ John Campbell, 1988, The Power of Myth

The emphasis of relationships replaced Newton's world of isolated parts. The discovery of relatedness depended on two assumptions. First, the universe was seen as fundamentally indivisible, a "flowing wholeness" as advocated by David Bohm and Niels Bohr (Briggs & Peat; 1989, p. 29). The second assumption was the universe was a participatory universe. Warren Heisenberg in the uncertainty principle emphasized the intervention of the observer in the system of the observed. John Wheeler (1979), a contemporary physicist, expressed these ideas eloquently:

> We had this old idea, that there was a universe out there, and here is man, the observer safely protected from the universe by a six-inch slab of plate glass. Now we learn from the quantum world that even to observe so minuscule as object as an electron we have to shatter that plate glass; we have to reach in there...so the old world observer simply has to be crossed off the books, and we must put in the new word participator. In this way we've come to realize that the universe is a participatory universe (in P. Buckley & F. Peat, A Question of Physics as cited in Peat, 1987, p. 4).

As a method, grounded theory—or more specifically for this study—epistemic inquiry stressed the reciprocal relationship among data collection, analysis and theory (Strauss & Corbin, 1990, p. 24). The researcher did not begin with a theory and then proved it with selective use of data or controlled variables; rather the researcher began with a field of study—the process of learning—and relevant constructs emerged.

The data for this study were derived from (1) twenty-six hours of participant observation, (2) fifteen indepth interviews with students in a public school classroom and (3) a multivocal review of literature. In order to understand the individual steps of this research, a chronological overview of the study might be helpful:

1. For twenty-one years, I had been a classroom teacher or an administrator in public schools. I had completed two advanced degrees in education as well as pursuing my doctorate in curriculum supervision. I felt the immersion requirement and professional experience for theoretical sensitivity had been fulfilled.
2. I became interested in chaos theory and complexity theory after readings in quantum physics and other literature suggesting applicability for the field of education in general and for curriculum and learning specifically.
3. I completed an indepth study of the career of Esther Thelan, a self-described chaos theorist focusing on early childhood motor development. This study revealed the radically different view of the child and learning from her earlier mechanistic strategies.
4. After reading Leshan and Margenau's (1982) <u>Einstein's Space and Van Gogh's Sky</u>, I constructed a theoretical framework to explore chaos theory further.
5. Observing and participating in the learning of trigonometry in an advanced high school math class for 26 hours, I attempted a learning catch-up of advanced mathematics. This personal experience—which I found very frustrating—provided a background in which to relate to the students' experiences.

6. After limited acceptance as student, I then conducted fifteen indepth interviews with volunteer students from the advanced mathematics class. Through a set of pre-designed questions, I examined the learning process from the students' perceptions.
7. During this time and through the completion of the study, I continued to read literature randomly selected from a multiplicity of sources (e.g. biological, educational, physical sciences, medical, business). These readings covered more than ten years of publications.
8. After completing the interviews, I transcribed the complete interviews from recordings and notes (see Appendix A for interview questions and Appendix B for a sample interview). I began a comparative analysis and coding procedure using grounded theory as suggested by Strauss and Corbin (1990). This comparative analysis included matrix and axial codings.
9. Using a modified framework describing chaos theory, I felt the findings suggested chaos theory could be used in understanding the learning processes within a classroom context and could possibly describe learning processes in general.
10. I began a review of learning theories coding relevant quotes but not limited to supportive data of the relationship of learning and chaos theory. I extended the data base for falsification of premises and to have a better understanding of the learning processes, terminology, competing theories and applications to the classroom. At that time I no longer used the grounded theory matrix and axial coding.

11. Review of the learning theories gave little substantiation or refutation of the findings of my study. I began looking more closely at complexity theory. I found chaos theory provided the language, but not always the substance for the learning process. The umbrella of complexity theory included chaos but incorporated a much wider body of literature and findings. The mathematics and the deterministic orientation of both chaos and complexity theories seriously questioned my original findings.
12. I then began looking at brain research. Gerald Edelman's (1992) Bright Air, Brilliant Fire and Fritjof Capra's (1996) The Web of Life significantly altered my original constructs.
13. Finally, I examined Eric von Glasersfeld's writings on radical constructivism to compare and contrast my philosophical premises detailed in this epistemic inquiry of curriculum.

The Participant Observer

> All men have the stars…but they are not the same things for different people. For some, who are travelers, the stars are guides. For others, they are no more than little lights in the sky. For others, who are scholars, they are problems. For my businessman they were wealth. But all these stars are silent. You—you alone—will have the stars as no one else has them—
>
> ♦ Antoine de Saint-Exupéry, 1942, The Little Prince

I derived the initial data for the grounded theory involving chaos and learning from the methodology of participant observation within the classroom. In another grounded theory study, the following quote illustrated the contrast of the analytical approach with qualitative research of participant observation:

> The traditional empiricist considers himself (as a scientist) to be the primary source of knowledge, and trusts his own senses and logic more than he would trust his subjects. The participant observer, on the other hand, considers the interpretations of his subjects to have first importance....By taking the role of his subjects he recreates in his own imagination and experience the thoughts and feelings which are in the minds of those he studies (Bruyn, 1966, The Human Perspective in Sociology, p. 12 as cited in Janisick, p. 23).

The qualitative data collection began with participant observation. I received permission of the classroom teacher (identified as Mr. Sine) and of the public school administration to observe one hour daily in an Advanced Placement Trigonometry/Algebra III class at "Someplace High School." "Someplace," a public high school, grades 9-12 was located in a commuting suburb of a Midwestern metropolitan city. Enrollment was 1,400 primarily white middle and lower middle Caucasians and over 100 staff and support personnel. Most of the faculty had master's degrees; no one on staff had an earned doctorate. The only minority staff member was an American Indian.

Of primary importance was the dual role of participant/observer. I had no experience with this level of mathematics. Although educated with a broad liberal arts background which included most subjects taught at the secondary level, I had always been interested in achieving higher mathematical skills, but had never taken the opportunity. I had hoped if the students realized I, too, was engaged in the learning process as well as meeting the requirements of the class, I would fulfill the requirement of participant. I would be seen as a student rather than in my professional role as a teacher.

Secondly, the class offered what traditionally would have been considered an optimum learning environment. The students enrolled in this elective mathematics course after fulfilling certain prerequisites of course work and cumulative grade point. Classroom numbers were small in comparison to most other classes; twenty-two students were in the class. Most students were native to the area; most had attended school in this district the majority of the time. Classroom disruptions were minimal, and the class as a whole exhibited a cooperative spirit in learning. However, I falsely assumed a more homogeneity profile of the students. The students' interests, personal family history, goals and academic success were as varied as any classroom. (See Appendix C for demographic information).

I also assumed the instructor and content were traditional; therefore, I could eliminate many biases that favored new and/or experimental approaches in teaching. Although I focused on intrinsic student dynamics and interactions in the process of learning, the participant observation revealed the personal feelings of the students towards the content, instructor, and/or methodology dramatically biased the students' definitions of the learning process.

Finally, mathematics, perhaps above all other knowledge domains, had been traditionally viewed as representative of linear and nonrandom understanding involving formal step-by-step processes. Although following the textbook orientation and order, the students followed very different approaches using independent study, collaborative and cooperative group work, and random trial and error. Also, throughout the observation, I noted Mr. Sine actively encouraged students to use diverse methods to arrive at the answers as well as complete the practices in the classroom. He worked more in the

Vygotskian manner of zone of proximal development than in any other pedagogical orientation.

I used a journal format to record the student behaviors, student interactions, and teacher/student relationships during this time period. I noted not only the events of the classroom, but I also participated in the classroom discussions (albeit limited) and completed the assigned classwork and homework. (However, I did not take any tests during this period.) The participant observation basically provided access, exploration of the subject, and a brief exposure to my own initial learning frustrations of an unknown content area. Most observations were limited to global incidents and specifics to subject matter. As a participant, I attempted to learn trigonometry. I desired to be more cognizant of the students' discoveries, limitations and frustrations. I wish I could say learned. I did not feel I learned how to work my scientific calculator efficiently, much less actually learned trigonometry!

Indepth Interviews

> There are no foolish questions and no man becomes a fool until he has stopped asking questions.
>
> ♦ Charles Steinmetz in Robert Olson, 1986, The Art of Creative Thinking

The participant observation allowed a relationship to form between the students and myself and provided insight in my own struggles with learning. The second methodology, fifteen indepth interviews, grounded the creation of the definition for learning. Traditionally, students had been viewed as passive recipients of knowledge within the classroom. In this context, Roegholt (1993) suggested as consumers of learning, students applied school learning only to school contexts. She felt students were unable to form relationships with classroom activities and everyday experiences.

I discovered Roegholt to be completely incorrect. How the students separated school learning from everyday experiences depended totally not in the general context of school, but rather on how they viewed this class specifically and how they viewed learning in general. These indepth interviews, used to discover how students involved themselves in the learning process, proved to be the key to the entire epistemic inquiry.

Strauss and Corbin (1990) suggested total transcription of the interviews (p. 30). I followed their suggestion. I took field notes during the interview process, but after an initial analysis of the field notes and the completion of the transcriptions of the taped interviews, I found the field notes to have glaring biases. I tended to be looking for specifics and recorded those confirmations of personal biases quite accurately, but I failed to record many statements from the interviews that led to later significant constructs.

In coding the transcriptions, I followed Clifton Conrad's (1982) suggestions. The main critiques of Glaser and Strauss were their failure to provide a detailed guide for researchers in grounded theory, especially in the coding process. Using the term " the constant comparative method," Conrad identified Glaser and Strauss's four overlapping stages; yet Conrad succinctly described methods to be used (pp. 241-242). I followed Conrad's suggestions.

The first stage was the collection of data and coding into as many categories of analysis as possible. Categories were "abstracted with other data incidents" (p. 241). Then as concepts were developed, theoretical properties of these concepts were considered: dimensions, relationships and conditions where concepts were pronounced or minimized. The first and second stage blended as data incident comparison became comparison of properties of concepts. The third stage was a "continuing analysis and further refinement of concepts and relationships" leading to theory development (p. 241). Finally, after theoretical saturations had been met, the theory was presented in "discussion format or as a set of propositions" (p. 242). The emergent theory controlled further data collections.

Coding

> And, of course, when you discover something like that it's like discovering a tooth with a missing filling. You can never leave it alone. You have to probe it, work around it, push on it, think about it, not because it's enjoyable but because it's on your mind and it won't get off your mind.
>
> ♦ Robert Pirsig, 1974, Zen and the Art of Motorcycle Maintenance

I believed I followed Conrad's four-step process throughout the epistemic inquiry; but I only formally coded the fifteen interviews to begin the inquiry process. The coding became a three-step process for each of the fifteen interviews. I looked first for descriptors of the population sample (e.g., gender, race, interests) and then completed a brief summary chart of the questions. Finally, a color coding of the interview was completed looking for positive and negative feelings, educational jargon, individual descriptors of learning, behavioristic or mechanistic incidence, and possible chaotic indicators.

The color coding worked much more efficiently than frequency counting. I could look for patterns and themes within the interview by quick evaluation after completing the process using marginal notes for referencing.

Red Flags

I used a red flag method to box any words I might have missed such as "never," always," "it couldn't be possible" (Strauss & Corbin, 1990, p. 92). This approach provided limited new information.

Axial Coding

The actual development of theory from data emerged from the following step. Axial coding was defined as "a set of procedures whereby data is put back together in new ways after open coding. The researcher utilizes a coding paradigm involving conditions context, action/interactional strategies and consequences" (Strauss & Corbin, p. 96). I modified a theoretical framework suggested by

Leshan and Margenau (1982), and I defined chaos theory into six major constructs: (1) simplicity, (2) extensibility, (3) multiple connections, (4) space and time, (5) causality, and (6) elegance. The color coding of the indepth interviews followed these constructs.

Matrix Coding

I transferred the axial and selective coding to matrix diagrams according to guidelines suggested by Strauss and Corbin (pp. 217-223) except I did not use memos as part of the analysis (See Appendix D for an example of this matrix coding—behavioristic vs. chaos descriptor incidents). I compared the summary table for properties abstracted during the comparisons of incidents. These properties partially defined the subsequent research of multivocal literature.

Multivocal Literature

> If psychology is to get ahead in understanding human nature and the human condition, it must learn to understand the subtle interplay of biology and culture. Culture is probably biology's last great evolutionary trick.
>
> ♦ Jerome Bruner, 1996, The Culture of Education

Reviews of literature typically summarized findings of recent professional journal articles with similar methodologies. Systematic procedures, such as meta-analysis, best evidence synthesis, and the case survey method, addressed application of reviews focusing primarily on empirical literature. By omitting other sources of information, I believed many relevant topics of education were not adequately addressed.

In contrast to traditional empirical reviews, multivocal literature was a relatively new procedure. In 1991, The Review of Educational Research dedicated an entire publication to multivocal literature. As the volume and access to information have increased, the current researcher needed to have skills in evaluating a larger pool and variety of informational sources. Included in this journal was an article by Ogawa and Malen (1991) specifically addressing rigor in review of multivocal literature. Their definition clarified the terms multivocal and rigor:

> Multivocal literatures are comprised of all accessible writings on a common, often contemporary topic. The writings embody the views or voices of diverse sets of authors...appear in a variety of forms...reflect different purposes, perspectives, and information bases....Rigor involves adherence to principles and procedures, methods, and techniques that

> minimize bias and error in the collection, analysis, interpretation, and reporting of data (p. 265).

Grounded theory accepted reviews of literature as data sets where findings of the studies were the equivalent to a response in a survey item (Ogawa & Malen, 1991, p. 267). In fact, these two authors cited Glaser and Strauss's (1967) emphasis that printed materials were "voices begging to be heard"; and literature reviews should be used as a form of original research. Ogawa and Malen suggested researchers had traditionally under-utilized viable sources of information which were "equivalent to the anthropologist's informant or the sociologist's interviewee.... In those publications, people converse, announce positions, argue with a range of eloquence, and describe events or scenes in ways entirely comparable to what is seen and heard in field work" (p. 163). However, Ogawa and Malen contended the major sources of bias and error were the exclusion of relevant articles or specific information. The primary purpose of multivocal literature reviews was to "inductively generate rather than deductively confirm, insights regarding the phenomenon of interest" (p. 271).

My qualitative review of multivocal literature did not produce definitive answers; however it identified complex issues. The literature of chaos and complexity theories, learning and neuroscience were complex by volume and content. It was my intent to develop "cogent, detailed portrait[s] ...and seek to preserve the subtle nuances and to accommodate the entangled web of forces that interact to produce the patterns apparent in real-life context" (Ogawa & Malen, p. 276).

THEORETICAL SATURATION

I saw a medley of haphazard facts fall into line and order....
"But it's true," I said to myself. "It's very beautiful. And it's true."

♦ C. P. Snow, 1963, The Search

The question, critical to grounded theory, was how long does the researcher continue the collection of data and to what extent? Strauss and Corbin (1990) inferred that at some point new information ceased by providing a general rule "to sample until theoretical saturation of each category [was] complete" (p. 188). They outlined three considerations for the saturation of categories—no new or relevant material emerged; the category development was dense ("...all of the paradigm elements are accounted for"); and the relationship between categories was well established (p. 188).

In the Cartesian/Newtonian worldview, knowledge could be achieved with absolute certainty and finality. Strauss and Corbin's assumption of theoretical saturation violated, however, the paradigm of approximate descriptions. This inference also violated my personal view of learning on any subject. For emphasis, I revisited Capra and Steindl-Rast (1991): "...in the new paradigm, it is recognized that all concepts, theories and findings are limited and approximate" (p. xiv). Specifically as I studied emergent sciences, total saturation was not possible; but I did believe reasonable saturation was attainable. Intricate and elegant patterns appeared as the inquiry of dynamic learning processes evolved.

Ethical Considerations

> During the scientific revolution in the seventeenth century, values were separated from facts, and ever since that time we have tended to believe that scientific facts are independent of what we do and are therefore independent of our values.
>
> ♦ Fritjof Capra, 1996, <u>The Web of Life</u>

> The path of the learner should also be a path with heart.
>
> ♦ Susan Drake, 1991, "The Journey of the Learner"

The primary ethical problem of monitoring the fine line between my professional role as teacher and role as student/learner emerged repeatedly during the participant observation and indepth interview processes. I knew this fine line might be tested when I observed undesirable student behaviors or when I faced conflicts because some of the students were concurrently enrolled in my own classes. I hoped as I gained students' confidences and trust, this concern would not significant. This dilemma, however, was never completely resolved. Throughout these processes, students still expressed concern for "what I wrote down" and "who would see?"

To address more formally these student concerns, I took about thirty minutes of one class period explaining to all the students I was attempting to understand the process of learning from the student's point of view. Before asking for volunteers for the indepth interview process, I explained information from the interview might be used for my dissertation research; but all information would be strictly confidential. Before each taped interview, I reiterated the confidentiality and limited use of the information. The tape would not be played except to verify my notes that I took during the interview. The interview would in no way affect grades, and no names would be used in the research document. Participation for the interview process and for each question of the interview was voluntary.

Limitations

Who dares to teach must never cease to learn.

◆ John Cotton Dana, 1995, How the Brain Learns

Perhaps I was overemphasizing the effect of the process because I was comfortable the indepth interviews were shared in an honest and meaningful manner, and methodology followed was rigorous and extensive. Students voluntarily coming for interviews one hour before or after school gave a sense that they wanted to be involved in the research and were more than willing to help in any way possible. At all times I attempted to maintain confidentiality of the students and their individual behaviors, but I was keenly aware of the limitations of my findings because of a priori attitudes held by students, the classroom teacher and myself in the educational setting. I did realize that my teacher role was never completely ignored or disregarded by the students.

One of the most difficult problems occurred when Mr. Sine became seriously ill. I could not attend class for ten days because of policy and procedures. I could not be in the class as a certified teacher with a substitute hired for the position. The ethical concern here was legal and totally unexpected.

The second difficulty was the length of time elapsing while conducting my study. I attempted to bring all research to a current level, but biases and constructs from the early studies seemed to influence findings in new research. I continually had to question whether I was following an inductive path, or if I were deductively looking for confirmation. However, because I was aware of this possibility, I strove to utilize the grounded theory constructs. Ultimately, as part of a phenomenological inquiry, the personal reflection of my own learning always challenged presently-held beliefs and future values.

It is good to have an end to journey toward/ but it is the journey that matters in the end.

- LeGuin, 1994, source unknown as cited in Silverstein, 1974

INTERLUDE 2

The Mythic Hero: Prigogine in the Classroom

> For centuries the poet has sung of [the student's] near infinitudes; the theologian has preached of his depravity and hinted of his participation in the divine; the philosopher has struggled to encompass him in his systems, only to have him repeatedly escape; the novelist and dramatist have captured his fleeting moments of pain and purity in never-to-be forgotten esthetic forms; and the man engaged in curriculum has the temerity to reduce this being to a single term—"learner."
>
> ◆ D. Huebner, 1966, <u>Language and Meaning</u>

I began my journey into the student's world with the qualification of <u>qualia.</u> Edelman (1992) interjected his biological theory with an explanation of qualia, a "collection of personal or subjective experiences, feelings, and sensations that accompany awareness" (p. 114). Qualia was that highly individualistic quality limiting the sharing of a personal experience. I could never completely share what I directly experienced to another individual or observer. I could report the experience; but because the experience was relative to my personal context, it would be partial and imprecise. Edelman reminded me there was "no qualia-free scientific observer" (p. 115).

From the qualia of the participant observer, I turned to phenomenology. Garrison (1988) reminded me phenomenology was a science concerned with the "nature of experiencing" (pp. 124-125). Public action and private experience were two different realities of psychological life. Once a private experience was told, the translation radically altered the event I called experience. The private action could not be shared; it could only be described and interpreted within basic methodologies. Garrison asserted that a "single event may participate in multiple realms of interpretation and belong to several different public realities" (p. 125). So, before beginning, I qualified the qualia of each individual indepth interview.

I would like to view these interviews more as a dialogue rather than an interview. The term dialogue implied an equality absent in the term interview. I wished not so much to have my questions answered as I wished to discover patterns within the process of learning. I wished to discover more about myself through these students, and what it meant to be a life-long learner. Perhaps, the student also learned about himself or herself in the process.

I have moved into the qualia or private arena of the student. The emphasis focused on the qualitative and subjective. John Holt (1995), in his book How Children Learn, expressed this idea eloquently:

> What we want to know, we want to know for a reason. The reason is that there is a hole, a gap, an empty space in our understanding of things, our mental model of the world. We feel that gap like a hole in a tooth and want to fill it up. It makes us ask How? When? Why? While the gap is there, we are in tension, in suspense. Listen to the anxiety in a person's voice when he says, "This doesn't make sense!" When the gap in our understanding is filled, we feel pleasure, satisfaction, relief. Things make sense again—or at any rate, they make more sense than they did. When we learn this way, for these reasons, we learn both rapidly and permanently.

> The person who really needs to know something, does not need to be told many times, drilled, tested. Once is enough. The new piece of knowledge fits into the gap ready for it, like a missing place in a jigsaw puzzle. Once in place, it is held in; it can't fall out (pp. 187-188).

The students affirmed Holt's view of learning as filling the gap made ready. Rather than practice and repetition, they described learning as it "just seems to click in my mind. I can hear things just a couple of times, and it's that way in math…" (Student VI). In contrast, rote and drill practice was just to get by: "Like rote, just kind of drill in your head type of thing….Rote memorization is for the time being to get you by. You know you are not really going to use it later" (Student VI).

Student VIII related his basketball skills: "It just comes to me. I don't have an explanation of everything." Student XI described what it means to learn trig: "To learn trig? The method that I learn. You have to be able, in order to learn and retain it (the way I look at it if you don't retain it then it's not worth learning) you've got to see it in your own mind instead of getting all these formulas and spitting them back. You have to see how it works and what they are actually doing and say, 'Yes, that makes sense.' I can see instead of just a formula."

"I can see! I can see!" Were we seeing the "Ah, Eureka" experience? Student IX succinctly described her own experience, "Wow, I actually got this !" Or, the eloquent description of Student XV and entropy—the energizing force that sustained the universe and man's thinking capabilities--summarized in one incident:

> I am sitting there in my room on my desk and I have all my information down that I need. OK, how am I going to do this? And it took me three

hours to get this problem done. I just sat in my room. Didn't eat dinner, didn't do anything and I just looked at the problem and tried it and erased holes in my paper and everything trying to figure it out. Finally I got it! Like I jumped out of my room and my sister was already asleep because it was so late at night. Did a little dance around the room and everything. It made me so excited and I went back to class, "I got it! I got it!"

Complexity, chaos, self-organization all still seemed possibilities. These samples were nonrandom; the classroom, only one of thousands across the country. Conducted within grounded theory methodology, the intent was not to finalize the theory, but to see if the search were still relevant.

The Sampling of the Fifteen

> And this is a general phenomena: the complexity, richness and meaning of the behavior of an organism is not a feature of the operations of its nervous system, but of the historical circumstances of its living.
>
> ♦ Humberto Maturana et. al., 1995, "Brain, Language and the Origin of Human Mental Functions"

The indepth interviews were used as dialogues for our understanding of the learning processes. I had chosen to place these comments in an interlude to prepare the reader for returning to the classroom and the realities of practice. I actually did the participant observation and indepth interviews before the multivocal review of literature. I wove the students' voices throughout the multivocal chapter to give them credence to their personal observations. Their voices stood among and substantiated the authorities in the fields of psychology, biology, and the neurosciences.

I also in my personal journey realized the students were the reason for my quest. I knew some of them as my own students, but most I met as a participant observer in the advanced trigonometry class. As I answered their questions, "Why are you here?", I tried to have them understand I was attempting to understand the learning process as they revealed it to me. I asked for volunteers; these fifteen responded immediately without noticeable hesitation.

Although the class was selective, and enrollment only possible with prerequisites and high grade point average, the demographics of these fifteen students were very similar to the student population as a whole in "Somewhere," a suburban Midwestern city. According to the recent "School Improvement Plan 1998" (approved April, 1998), this once rural community was now a rapidly growing suburban area. The school district population was 25,000 with a total K-12 enrollment of 6,200 students. Demographic projections indicated continual growth. Within this district, there were five elementary schools (K – 5 grades), two middle schools (7 – 8 grades), and one comprehensive high school.

The district population was predominantly white middle class with small representations of minorities, primarily Vietnamese. The educational level of the community was mainly high school graduates. Within the comprehensive high school, vocational, business and college preparatory curricula were available. Within the community and the school was a strong emphasis on athletics, but a quality program in music was also available. Many extra-curricular activities were provided. The high school was currently providing over 190 units of study which also incorporated courses possible from a wide area vocational-technology school.

Somewhere High School was built in a campus style similar to traditional community college with a complex of several separate buildings. Each of these buildings contained specific departments of study. The 1997-98 student population was 1,786 with a staff population of 144 certified and support personnel. When these interviews took place, the enrollment was slightly over 1,400 with about 100 certified staff. The difference in numbers was indicative of the very rapid growth of the district occurring more dramatically at the high school level than at any other grade levels.

The Individual Fifteen

You have brains in your head.
You have feet in your shoes. You can steer yourself
Any direction you choose.
You're on your own. And you know what you know.
And YOU are the guy who'll decide where to go.

♦ Dr. Seuss, 1990, Oh, the Places You'll Go

As stated before, these fifteen students were representative of the population in spite of the stringent requirements to get into the class. There were more girls (9) than boys (6); more white (11) than minority (4); and more juniors (13) with only one freshman and one senior. The majority had been enrolled in this same school district since kindergarten (10). Most of the students were heavily involved in extra-curricular activities perhaps explaining why more chose the early interview (10 at 7:30 a.m.) rather than the one after school (5 at 3:30 p.m.). Their interests ranged from musical (8) to academic (6) and sports (3). There were also nine students who indicated "other" interests.

However, in many ways these students did not fit the stereotypic high achiever often assumed by educators. Like their other counterparts in the general school population, only slightly over half came from traditional nuclear families (8). The others were in homes of varying degrees of divorced parents, step parents and step siblings, and others. Their parents reflected the educational level of the community. Only one parent had a college education. Although not all responded, only three students spent an average of two hours or more a night on homework even though all the students were enrolled in a demanding college preparatory program.

Attitudes towards the teacher, the class, and math in general also varied. Only six ranked the attitude towards the teacher favorably; yet ten stated they liked the class. The reason why was "because their friends were there." Only slightly over half (8) gave a favorable rating to math in general even though the same number of students had been in an advanced math program since the eighth grade. One student became <u>very</u> agitated when I asked about liking the teacher or the class although he did not elaborate what made him so uncomfortable with the question. The words used to describe the reason for liking or disliking the class also were interesting ranging from "algebra better, pretty easy, not fun, hard, difficult, practical, bizarre."

Recurring Patterns...Emergent Properties

> So we find divergence and convergence in evolutionary processes....One of the major questions, then in understanding cognitive development, learning and teaching is to understand the processes by which some evolutionary processes are convergent, thereby allowing some types of prediction, while others are divergent and therefore unpredictable.
>
> ♦ Gary Cziko, 1992, <u>Educational Researcher</u>

I followed the guidelines of coding carefully according to Strauss and Corbin (1990) looking for recurrent patterns. Through a method of color coding I marked the following:

1. Cognitive and Educational Terms
   (a) educational terms (e.g., school, class, Chemistry II)
   (b) learning terms (e.g., learn, memory, intelligent)
2. Affective Categories
   (c) positive (e.g., like, all right, pretty useful)
   (d) negative comments (e.g., very boring, nothing new, little above average)
3. Paradigm Indicators
   (e) behavioristic/mechanistic (e.g., same stuff over and over, before I get to college, practice)
   (f) chaos indicators (e.g., different people have different answers about the way they go, process by which a person assimilates, idea about the way they go, Wow, I actually got that one!).

I was not interested in frequency counting; I only was looking for overall patterns for explanatory possibilities. Not one of the fifteen students were using just behavioristic or just chaotic terms. Individual questions had some inherent consistency of coding, but none of the fifteen kept a consistent coding throughout all thirteen questions.

Students used numerous words referencing school (e.g., "trig," "junior varsity," "AP Algebra," "homework") that usually only appeared in educational context. This word choice was understandable because it was the context of the life of their present experience. I had earlier in this writing called this language <u>schoolese</u>.

The one significant pattern, I did discover, however, was if the students began to describe learning in Question 7 (Can you describe what it means to you to learn trig?), this choice of imagery was used predominantly through the remainder of the questions

(Students I, III, IV, VI, X, and XIV). If that pattern did not emerge early in the discussion of the learning process, most generally the result was a mix of deterministic and a sprinkling of chaos. For example, I noted and coded short phrases of chaos in the dialogue of Student VI. He continued to respond this way and then abruptly began describing some behavioristic and negative occurrences:

> Kind of putting things in perspective and figure out how they all fit together and uh, the reasons behind it. If I can understand where it's coming from, it's usually makes it makes easier to do and comprehend (chaos, pattern, space and time coding). [He referred to finding the practical side several times.] English, I can see the practical side of English but as far as history and science goes, it doesn't really seem like that down the road whether I know a date or know who discovered something. I could; I could be wrong....Yeah, I'd say like in history and sciences trying to learn more memorization type things, just....Maybe I don't quite understand it, but I just take it...that's the way it's going to be. Like rote, just kind of drill in your head type of thing (behavioristic, educational terms, space and time).

He then picked back up on the words of the chaotic paradigm and describe learning in strong images of repeating "Ah, Eureka" experiences:

> ...when you first start something you kind of feel you're in the dark but slowly as you learn...usually for me it will just all of a sudden hit me and I understand it and it gives me a pretty good feeling that I know how to do this. And this seems to help you to go further and do more....It will be like

> working on a math problem and you'll see the relationship of how everything interconnects and how everything fits together. And that's usually when it comes to my head, a little light comes on and my brain tells me I understand now.

He saw the pattern of learning; he felt good about it; and he wanted to go further. His discouragement was only when he didn't feel that requirements of the class were practical to him personally but more of the traditional drill and practice. Yet, he was not sure he should even question this methodology; he only revealed it was not consistent with what he would like it to be.

The Journey within the Classroom

> To the young mind everything is individual, stands by itself. By and by, it finds how to join two things and seen in them one nature; then three,then three thousand...discovering roots running underground whereby contrary and remote things cohere and flower out from one stem,....the astronomer discovers that geometry, a pure abstrctions of the human mind, is the measure of planetary motion. The chemist finds proportions and intelligible method throughout matter; and science is nothing but the finding of analogy, identity in the most remote parts.
>
> ♦ Ralph Waldo Emerson (source unknown)

I now go back to the classroom, to my journal of notes to allow the reader to visualize the time and place:

> The first day I walked into the class, the students were taking a test. Calculators were available and mechanical pencils and separate erasures were busy doing what students do—taking a test. All were neatly dressed, mostly in jeans and causal tops. Stuffed backpacks were haphazardly on

the floor. All were juniors except for two girls—one a freshman, one a senior. Five of these students were Vietnamese; one black descent, lightly colored. Same makeup with limited minorities as the entire school.

No talking as all were intently doing their own work. The only sound was one student tapping on the desk. One stretched his hands as if needed to relax. At this point I can't see faces for emotional responses because my seat is in the back.

One student is having noticeable problems with frequent erasures and grand gestures of sweeping off the fragments of erasure remains. No smiles were shown as the students turned in their papers. The different rates of completion varied almost thirty-five minutes.

Movement is limited restlessness as students wait for everyone to finish, but there is still no talking. One student gets through and begins humming. After being in the class for fifty minutes, one student now says "hi" to me.

The second day students enter, sharpening pencils and talking about a variety of subjects. One student makes a stupid remark, and no one responds. One student asks of me, "Substitute?"

The teacher enters, and friendly exchanges continue. "I love those suspenders, Mr. Sine." The language of trig is baffling to me, but I noticed some intent conversations between students are actually about trig! Most are actually ignoring the teacher's explanation and are working in small group interactions. Students already know what the assignments are going to be, so they are in various stages of completing the work. The teacher assistance is more at the individual questions than lecture explanation. Some are giving others a hard time for working ahead over the weekend. One student consistently does Spanish III during class. Students avoid eye contact with me, but sometimes try to glance at my notes to see what I am writing.

One student talks about her sister in college having a 102 average and asking another student if they give bonus in college. Neither knows.

"That one is really hard" [referring to a particular problem.]

"Ask him."

Lots of short quips and responses as if it were simply not necessary to talk a lot but yet understand each other. All appear to have a very positive working relationship.

...[Day 5] Six students are absent because of a band trip. I began to try trig. My notes are filled with examples of formulas and problems that I can no longer read. The emphasis in the class is repeated—the more complicated the problem, the more ways to work it.

The teacher encourages, "Some people are better at working identities...all of you did good work...work that out and you can quickly whip the whole thing out...."

My notes are on trig rather than on the students. I am really trying to understand. I noted where I found my own error and was really excited! There are no absolute deadlines in the class. Notebooks are turned in to record grades, but one student not finished with a fifty-problem assignment kept his notebook, and that was OK. It was not until today [Day 5] when I asked if I could watch a student do his work that someone else asked why I was there.

"What are you doing this for?"

"Part of my dissertation."

"OK."

CHAPTER 3

THE JOURNEYS OF THESEUS

Contemporary Complexity and the Mind Brain

> Science is breaking through now into the mystery dimensions. It's pushed itself into the sphere the myth is talking about. It's come to the edge…the edge, the interface between what can be known and what is never to be discovered because it is a mystery that transcends all human research.
>
> ♦ Joseph Campbell, 1988, The Power of Myth

An article in the Washington Post (1979) titled "The Cupboard of Ideas Is Bare" described the nation's most prominent thinkers unable to solve the nation's most urgent policy problems. According to Fritjof Capra (1982), this crisis of ideas was the result of a narrow perception of reality. He discussed the radical shift from the narrow perception of segregated and isolated specialties towards the complex and integrative systems view of life. I, too, believed the world is moving towards this more broadly interconnected biological view of emergent complexities.

John Holland (1998) described the necessity of changing of perceptions and methods in order to examine complex systems: "The search at this stage is a matter of intelligent probing, not a matter of runs and reruns yielding 'statistically significant relations.' The Baconian approach of gathering data until significant relations emerge is unlikely to work because the systems exhibiting emergence are so complex" (p. 242).

Students also realized part of the process was the struggle, not the final result. Student V shared her frustrations, her needing help from others to help her find her own—a way not necessarily the same for her as others:

> And everyone else thought it was so easy and I thought, "Oh, help!" [I] talk to [Mr. Sine] or [other students]. "Help me, please!" They usually explain it to me and I can ask them, "Will you explain it again?" I just keep going over it...different people have different answers or different ways about the way they go. Just because the teacher says this way that is not necessarily for everybody.

This epistemic inquiry could be also be described as another way to explain or as an intelligent probing. It began as a narrow look at chaos science and emerged as a complex view of a wide variety of diverse fields. Threaded throughout this multivocal review of the scientific, educational and psychological experts, I referred back to the classroom experts—the students. I attempted to provide recursive comparisons for the study's verification. These recursions were not the reruns of statistical data; each of the voices provided unique understandings in my journey to understand learning.

Initially, like many researchers (e.g., Gleick, 1987; Briggs & Peat, 1990; Hayles, 1990; Hall, 1991), I was enamored with the language of chaos and the possibilities of applications. Publications in respected educational journals also indicated chaos science had direct implications for curriculum and educational practice. However, repeatedly, the vocabulary rich with possibilities gave way to increasingly deterministic and mathematical solutions. Education theorists looked only at limited applications and arbitrarily sprinkled chaos vocabulary throughout their writing. The results were disappointing, and I had to look in other areas.

Student II also told me of disappointment in the classroom. She had to look other places than the trigonometry class for positive results. This same student who saw memorization as a way to "[prepare] for my future"—"pass a test"—"get ready for another <u>good class</u>"—"it's going to look good" responded flatly to one of my inquiries: "Gosh, I can't even remember what we worked on lately." The <u>weird</u> formulas she found in trig provided lots of stress—"so stressed out at school"—but all in all "that" wasn't applicable to her personal experiences. She then talked excitedly about working with children in a nearby burn center "outside of school…that was a great experience…I learned more in less time by working with the actual thing."

In searching for explanations through multivocal review, many writers looked for multiple ways of expressing these new and often paradoxical findings. Barrows (1991) in his search for the ultimate explanation or theory of everything looked first at myths. Hayles (1990) combined chaos science and literature as indicated by her title <u>Chaos Bound: Orderly Disorder in Contemporary Literature and Science.</u> Interestingly, Holland (1998) juxtaposed poetry and physics with the creative process and provided his reasoning why:

> When we look at the creative process, it's interesting to compare the two great <u>P's</u> of human intellectual endeavor, Poetry and Physics. Each produces deep insights into the world that surrounds us, but their disciplines seem <u>very</u> different. However, this dissimilarity makes even a

brief comparison useful in enlarging our understanding of emergence and the creative process (p. 218).

The Language of Complexity

> You don't see something until you have the right metaphor to let you perceive it.
>
> ♦ Thomas Kuhn, 1970, The Structure of Scientific Revolutions

Student IV attempted to explain the process of learning. She hesitated; she faltered with her explanation until she could find the right metaphor:

> Learning to me is, how I experience learning, is listening to a teacher. I think. I learn. I think. I learn....Uh, to me it's different [learning Trig] because trig is basically thinking. You think to solve a problem. American History, you are learning the information...but you're not really thinking a lot unless you're thinking about the past but not many people do. They just stay with what's in the book or worksheet but they don't do any extra thinking....

She certainly couldn't define learning through textbooks and worksheets, but she was having difficulty trying to explain learning in terms of trigonometry. She finally used the example of learning to play the piano to bring the process together:

> For instance, in piano. In trig, we have to, they give you, a problem and you have to use your knowledge and your mind to think about how to solve the problem. Well, in piano, the teacher would give you the music and you have to think how you are going to play it by what tone, what

beat, what dynamics, movement, motion and pedaling and everything. And you have to use your thinking to put these things all together to form the feeling of the music.

Language determined and organized perception (e.g., Capra, 1996; Leshan & Margenau, 1982; Maturana, 1998; Ruiz, 1998). Language always experienced a radical change in terminology and metaphor preceding and during a paradigm shift. Over twenty-five years ago, Kuhn (1970) popularized the term paradigm shifts. In order to understand the ramifications of a paradigm shift, his views were essential:

> The proponents of competing paradigms practice their trades in different worlds....the two groups of scientists see different things when they look from the same point in the same direction. That is why a law that cannot even be demonstrated to one group of scientists may occasionally seem intuitively obvious to another. Equally,...before they can hope to communicate fully, one group or the other must experience the conversions...[called] a paradigm shift. Just because it is a transition between incommensurables, the transition between competing paradigms cannot be made a step at a time, forced by logic and neutral experience. Like the gestalt switch, it must occur all at once (though not necessarily in an instant) or not at all (p. 150).

An example of this paradigm shift began in the 1920's with quantum physics which has now expanded to a much broader cultural context (Capra, 1996). Not only did quantum physics introduce new vocabulary of quarks, quantums, and photons, many of the basic views of the Newtonian universe were no longer relevant. In 1952, Heisenberg was still trying to reconcile Newton's mechanics and Einstein's quanta. Finding Newton and Einstein irreconcilable, Heisenberg's uncertainty principle posited randomness and uncertainty in the world through differential equations. Not only did new scientific formulas appear; new contextual language for dynamic movement, interaction and transformation also was created. Capra (1996) stated that now the language had emerged to help to understand the "complex, highly integrative systems of life"—dynamical systems theory, the theory of complexity, nonlinear dynamics, chaotic attractors, fractals, dissipative structures, autopoietic systems (p. xviii). Thus with careful use of homologies, the Koch's snowflake, the red spot of Jupiter, the Lorenz attractor and others united with the students' self-definition of learning in the new language of emergent complexities.

But, I was even going beyond the mythical framework, beyond the introduction of homologies to understand the process of languaging and its importance to the process of learning itself (Ruiz, 1998; Maturana & Varela, 1987). I individually created my own unique reality of the world—a reality that was valid but fluid, referring back to Cobb's (1977) term "worldmaking" and Bertalanffy's (in Capra, 1996) term "flowing balance—fliessgleichgewicht." This reality always operated in the present, but past experiences and future learning affected this dynamic process of continual change.

Languaging defined objects as a process of "linguistic distinctions of linguistic distinctions" (Capra, 1996, p. 290)–similar to metacognition of thinking about thinking. As explained in Chapter II on phenomenology, only the human species can reflect on experiences through linguistic definitions embedded in cultural and personal contexts. Once I defined objects, possibilities for abstract and complex thinking was then created.

Meaning was derived from the pattern of relationships of these linguistic distinctions; and the abstract concepts of reflection and consciousness itself appeared (Capra, 1996, pp. 286-293). Student X explained: "Well, I would say when I can go out and not be in a class taking a test, but I can be out in the world and come across where I have to figure something out....I sort of take that as when I have learned anything. When I can actually use it in the world and I ...have to do something, then I know I have learned it."

As Student V concluded: "Just the real good feeling like when you've finally done something and you have done it right....I think learning is book learning, but I also think learning is experiencing new things, being able to go out and to try something you have never tried before."

Maps of the Mind

> So the person who says he is a machine is mad, while many of those who say men are machines are considered great scientists.
>
> ♦ Hampden-Turner, 1981, Maps of the Mind

The students in their attempts to define learning talked of many things—going forth into the world, the subtle interplay of feelings, the desire to attempt the unknown. Charles Hampden-Turner (1981), in his creative text Maps of the Mind, showed interrelated, yet evolutionary thought related to the question, "What is the mind?" I first paraphrased his question to "What is learning" indicating the interchangeability of terms. In the later part of this section, I will rephrase his question to "What is the mind brain?" Hampden-Turner's introduction was also a relevant introduction to this series of questions:

> 'What is mind[learning]?' is a question that has intrigued people from the earliest times—indeed for as long as man has considered the possibility of

mind[learning] at all. It is the first truly philosophical question which comes with the dawning of self-consciousness....with the notion that one is prior to the many, that there must be some unitary reality behind multiple appearances. I believe man is his own metaphor, whose self-image fulfills itself in unforeseen ways....This...is a plea for the revision of social science, religion and philosophy to stress connectedness, relationship, organicism and wholeness, set against the fragmenting, reductive and compartmentalizing forces of the prevailing orthodoxies (p. 8).

Not only did I create reality through languaging; I also limited reality. Even though Hampden-Turner discussed wholeness, he compartmentalized levels of the mind [learner] to clarify discussion. In my attempt to discuss his findings yet avoid implications of his hierarchy, I believed a wide variety of psychological and philosophical heritages can be briefly examined—an examination necessary before other forms of research became viable. A valuable homology of maps of the mind was paraphrased from Hampden-Turner's text (pp. 6-7):

1. At this level, the mind struggled for emancipation from servitude to gods or the laws of Newtonian mechanism of a predetermined universe (e.g., Greek humanism, philosophy of T'ai Chi, Saint Augustine, Descartes, Newton, Darwin, Weber)

2. At the psychoanalytic and existential level, the privacy of the mind shaded consciousness, preconsciousness, and unconsciousness which

undergirded differences in thought and behavior (e.g., Freud, Jung, Fromm, Kierkegaard, Rollo May, Sartre, Silvan Tomkins).

3. At the physiological level of brain functioning, thought and behavior had a physiological, anatomical, and psychological basis (e.g., Wilbur Penfield, Pape-MacLean theory of brain evolution, the left/right brain, Karl Pribram).

4. At the creative level, the capacity of combination and reorganization transcended the mechanism (e.g., William Blake, Getzels, Arthur Koestler, Fran Barron, Jay Oglivy, J. P. Guilford).

5. At the psychosocial level, learning was from and encompassed relationships with others and the environment. Earlier levels were subsumed (e.g., Rogers, Maslow, Buber, Lewin, Erikson, Piaget, Kohlberg).

6. At the level of communication, language and symbolic interaction, structures—linguistic, visual, emotional—were the basis for understanding Patterns were revealed from widely diverse cultures (e.g., Russell, Whitehead, Chomsky, Fuller, Benedict, Osgood, Hampden-Turner).

7. At the level of psychobiology and cybernetics, learning was examined in the context of the environment and mutual feedback (e.g., Bertalanffy, Koestler, Bateson).

8. At the paradigmatic level, a priori assumptions of the nature of man and the universe and self-conciousness, methodologies and epistemology revealed facts and patterns (e.g., Hegel, Marx, Kuhn, Thom).

9. At its most inclusive level, learning was viewed as adhering to the structure of myth, institutions and cultures.

Reviewing the delineation, the conclusion must be that the search for one theory – or the right theory—was impossible. All the constructs were requisite for an integrated view of view of learning. Even looking back at Aristotle and Plato, forefathers to modern learning theory, the idea of one theory would be antithetical. According to Hampden-Turner, the major difference between the Greeks and the Judeo-Christian culture was the monotheistic view; "hence monolithic in our theorizing and monadic in our conceptions" (p. 14).

If I were willing to examine further, the Greeks offered also the connection of chaos and order to learning. According to Hampden-Turner, the "unbreakable relationship between men, gods and nature and even including death was the "soul" (p. 14). The word "chaos" literally meant "gap," a breaking of that unitary relationship.

The Greeks also provided a historical basis of a patterned universe as well as the idea of complementarity. Anaxagoras, the teacher of Socrates, suggested the "mind [pervades] a patterned universe, wherein every value contains the seeds of its opposite" (Hampden-Turner, p. 19). Descartes ultimately shattered this pattern by splitting the image of the mind from the body, subject from the object, and knower from the known. Ryle (1949) discussed this Cartesian dualism within the metaphor of a university:

Cartesian dualism was "a category mistake." Imagine a visitor to a university who is shown lecture halls, laboratories and libraries, only to ask, "But where is the university?" Mind, like the university, is in all the things seen, and in seeing itself. It unites the knower and the known, subject and object and all relationships thereto. We are not either free or determined, but both since mind through language has multiple levels (The Concept of the Mind, London: Hutchison as cited in Hampden-Turner, p. 33).

Quantum physics expanded this principle through Niels Bohr's complementarity principle and the Copenhagen interpretation (Casti, 1989, pp. 442-443). In physics, according to Casti, all attributes of objects were contextual. Attributes could not be described outside of the measuring situation. The complementarity principle stated wave properties or particle properties would be observed depending on the measuring device. Coupled with Heisenberg's uncertainty principle, the Copenhagen interpretation became a joint relationship with the object and the process of measuring dynamic attributes:

> In other words, this [interpretation] is an intrinsic property of Nature, and that the observer, the measuring device, and the system to be measured form a whole that cannot be divided. More prosaically, we might express this wave-particle complementarity idea using Bohr's own phrase: "The opposite of a big truth is also a big truth" (Casti, 1989, p. 442).

Extending this homology, the learner experienced the world on the basis of prior experiences – the measuring device of the observation. Not only did these experiences frame the new learning, but past learning changed in the process. The individual, therefore, was transformed through the integration of seeing or perception, experience, and the contextual situation. However, the transformation did not provide absolute answers, only offered personal speculation. In a terse interview, Student XIII offered an unexpected profound statement: "… you know everything that's happened, but there are no definite answers, and there are no set equations on how things happen. You…always speculate."

Psychoanalysis and Myths

> There's no mythological symbol more potent in the American psyche than the open road. You see these commercials with fast, expensive cars zooming along empty roads. How do you change that part of our psyche?
>
> ♦ Bill Moyers, 1989, A World of Ideas

Was the student's speculation always conscious experience? Theories by Freud suggested awareness beyond conscious awareness. Jung contributed the idea of collective unconsciousness within the dimension of the brain structure itself:

> By collective unconscious Jung meant "the inherited possibility of psychical functioning…namely…the brain structure." This shared human heritage was quite unlike the dark chaos of the impulse world Freud had assumed. Jung's unconscious has a primordial structure and coherence, like a burial chamber of priceless antiquities which are lustrously revealed by the light of consciousness probing the darkness of the tomb (Hampden-Turner, p. 44).

I also wanted to emphasize Jung's view of the importance of brain structure, a physical structure of the brain connected to a wider subjective context of learning. He expanded these ideas to explanations for the importance of social context and for the necessary inclusion of myth and metaphor, for nuances of meaning. His acausal principle of synchronicity had strong implications for any insight into the complex learning processes (Briggs & Peat, 1989; Capra & Steindl-Rast, 1991; Hampden-Turner, 1981; Peat, 1987). Synchronicity was the "meaningful coincidence, significantly related patterns of chance" (Peat, 1987, p. 1). Was Student XIV referring to casual social encounters, or was he describing synchronicity? "I guess I couldn't really tell you when I've learned something. I guess when someone brings up a conversation and I can intelligently, you know, give my two cents worth and not say something really stupid. I can discuss it with them"?

Another student, Student IX, talked about the progression and permanence of learning: "Learning is when I comprehend new material and can recall it at a later time to use it again. It doesn't just, I don't just understand and then it leaves me." Another important psychoanalyst, Erich Fromm, evaluated the journey of learning as the process of greater potentials and qualitative changes. Like the arrow of time, the progression was forward, "to regress permanently to earlier patterns [was] to die within." All feelings, attitudes and motivation were subsumed to the "necessity to find ever-new solutions for the contradictions in [the human's] existence, to find ever-higher forms of unity with nature, his fellow [humanity] and [self]" (Hampden-Turner, p. 50-51). However, in contrast to Fromm, I strongly emphasized this progression <u>at all ages</u> of development was relative, lateral, constantly moving forward. It was not a hierarchical or stage-like movement.

Hebb's Structural Contribution

> Do not seek to follow in the footsteps of the men of old; seek what they sought.
>
> ♦ Basho, (1994), Little Zen Companion

Student VII looked at the options of learning trigonometry, "You can memorize those [examples in the book] and solve the problems or you can actually read the material in between the examples and use that instead....Learning is a process by which a person assimilates an idea or concept so that he can do it himself, so that he can understand it." None of these students, though, referred to the structure of the brain except in metaphorical terms, like "a little light comes on and my brain tells me I understand now" (Student VI).

Some researchers in brain-based learning and other theoretical constructs had attempted to sustain discussions of the physical structure of the brain; yet, most journal articles, I felt, still failed to convey why educators should seriously consider biological structure (e.g., Kovalik & Olsen, 1993; The latest...1997, NEA Today; Pinkerton, 1994; Springer, 1989; Sylwester, 1994, Sylwester & Cho, 1993). Written five years ago, yet very relevant today, Kovalik and Olsen (1993) offered interesting reasons why research on the brain had not been given full consideration:

> The "best available knowledge" about how the human brain learns has been knocking at the education's door for more than 20 years, yet we have been almighty slow about letting it in. Why? The reasons are numerous but chief among them are: 1) the conclusions of current brain research so contradicts traditional educational practices and pictures of how "it's

suppos'ta be" that we either ignore the information, misunderstand it, or simply fail to imagine how to implement it and 2) the massive inertia of the system with its resistance to change of any kind (p. 13).

Almost fifty years ago, Karl Lashley (1950), a noted but often discounted psychologist, published an important paper "In Search of the Engram" stating learning and memory were distributed diffusely throughout the brain rather than being localized in specific structures. Donald Hebb, one of his students, further suggested learning and memory involved real physical changes of structure in neuronal circuitry. (His theory of cell assemblies has now provided a framework for current neuroscientific research.) Although Hebb's terminology was similar to information processing, the idea of cell assemblies and structural change within the brain during learning was important to review. Hebb believed brain development—and thus learning—could be characterized as an increasing number of cell assemblies based on life experiences.

This concept of increased cell assemblies was more than just accretion of new learning, building up little bits of information step-by-step. I would suggest Hebb was referencing how the assemblies could transform past experiences into totally new ways of thinking. Student X attempted to describe this change after hearing a debate on a social issue: "I learned from their opinions. I sort of put their feelings together and came up with what I felt. I go in with one feeling and sort of build upon it or change it by learning newer things about it."

Capra (1996) referred to cell assemblies without mentioning Donald Hebb. He discussed mental space created by different brain functions, yet appearing as a single coherent experience (p. 292). He expanded this idea to Varela's concept of phase locking:

> …created by a resonance phenomenon known as "phase locking," in which different brain regions are interconnected in such a way that all their neurons fire in synchrony. Through this synchronization of neural activity, temporary "cell assemblies" are formed, which may consist of widely dispersed neural circuits…the fact that neural circuits tend to oscillate rhythmically is well-known to neuroscientists and recent research has shown that these oscillations are not restricted to the cerebral cortex but occur at various levels in the nervous system (pp. 292-293).

Hebb's hypothesis had also been found to be correct with cell assemblies identified as axional branching (Edelman, 1992). (Hebb felt, however, the efficiency of these assemblies deteriorated by the aging process—a premise now proven invalid.) Restak (1984) recounted a personal interview with Hebb. Hebb referred to his two-year-old grandchild Matthew as he explained his cell assembly theory:

> Matthew's experience with boats of any kind is so limited that at this stage in his life has not yet found a cell assembly that would correspond to the idea or to the experience of seeing a boat. In perhaps three years he will have an idea of a boat very well developed—that is, he will have a cell assembly or cell assembly groups corresponding to the different experiences of a boat as seen from the side, as seen from the front, as seen out on the water sailing, and so on….I spent a lot of time trying to think of a way in which the brain could function. All the theories that I knew made the brain out to be completely controlled by the things that were going on around it, by the sensory events that the brain was exposed to. But it

occurred to me about 1945 that the brain might be functioning independently of the messages it is getting from the outside. I came up with the idea that brain activity is actually the activity of a number of separate systems that I call cell assemblies. Thanks to these cell assemblies, activity can go on in the brain without any external stimulation at all (pp. 226-229).

Strangely, my own grandson—also named Matthew—was one of the reasons for beginning this epistemic inquiry. Out on my patio, Matthew watched birds' feeding their young in a nest. He commented to me the young baby birds were just like him—with a mother, a father, a home and "hungry." He had made a complex pattern based on his own life experiences and connected disparate concepts into one.

The Bisociating Mind

> The practice of Tantra does not mean the end of rational thought. It means the integration of thought based on symbols into larger spectrums of awareness. (Enlightened people still remember their zip codes).
>
> ♦ Gary Zukav, 1979, The Dancing Wu Li Masters

Earlier in this inquiry the Greek legend of Archimedes was retold introducing the "Ah, Eureka" most often observed in creative thinking or in the final stages of problems solving. After these disparate connections had been made, the results seemed obvious; however initially inventions and creations belonged to different disciplines or domains of thought (e.g., electricity and magnetism before electromagnetism; smallpox and milking cows before the cowpox immunizations). Examples of these syntheses demonstrated the

Gestalt idea of "the whole is greater than the part." Arthur Koestler (1964) described the merging of two disparate matrixes as the act of creation:

> ...a bisociation of two or more thought-matrices (or frames of reference) which were previously unconnected with one another....Instead of just colliding or contrasting, [the ideas] become permanently joined in a new creation, wherein the whole is greater and qualitatively different from the sum of the parts" (The Act of Creation, New York: Macmillan as cited in Hampden-Turner, p. 100).

A simple explanation clarified the bisociation process. An individual was attempting to solve a problem in frame A. Repeated frustration led to a jump in frame B. Finding the right "frame B" was major to the solution, but most often came when attention was "wandering causally and subconsciously among alternative frames rather than consciously focused on one" (Hampden-Turner, p. 100).

I believe that Koestler's bisociation was similar to bifurcation used in explanations of chaos theory. Patterns of thinking had a tendency to follow habitual paths until suddenly planes or levels of thinking jumped chaotically to a new phase space. (See Appendix E for diagrams of pitchfork bifurcations and successive bifurcations. These concepts will be expanded later in this inquiry in the discussion of chaos theory). Often this jumping occurred when heuristic devices or metaphoric images were used. Often the jump occurred totally unexpected.

Student X was responding to the interview question "Is learning trig the same as learning things outside school?" in a nondescriptive manner when she suddenly interjected a simile: "Like we had a girl that went to India and came back to school. Like beggars, I've never experienced that and I would say learning how to handle that would be just about as basic as having to learn trig because you don't know."

In addition to the concept of bisociation, Koestler believed in the "principle of ripeness," also an important concept to this inquiry. Disparate technologies or inventions separated by geographical locations offered a simultaneous joining when culture or the worldview was ready or ripe. Learning and creative thought, therefore, had historical and cultural contexts as well as individual creativity.

Finally, Koestler asserted the creation of theories often had commitment prior to support of facts. As an example of this commitment, he used Charles Darwin's recording his commitment to the theory of evolution prior to the voyage on the <u>Beagle</u>. Koestler viewed human knowledge as evolutionary, paradoxically both nonlinear and deterministic. He viewed both knowledge and biological evolution processes of "creative accretion":

> Bisociations are junctions which branch out like trees turned upside down. These holarchies...consist of holons...a synthesis of "whole" and "atom," so called because persons taking a stand at any junction and looking down will see parts below them, of which they are the whole or apex, while the same person looking up, will not see wholes above them of which they are a part. Not just human knowledge, but the biological and psychological realms in general are organized holarchies. We are the freest "at the top" of these inverted trees and most determined "at the bottom." Holarchies are therefore also subject to rigidity and inertia. Doing one to another may involve a radical undoing of habits and ways of thinking regarded as immutable (Hampden-Turner, p. 103).

In other words, a person consciously learned to drive a car or ride a bicycle. Soon the skill became a "habit-hierarchy of automatic responses." Once these automatic responses were formed, a person was then able to have creative thoughts while driving or riding. The skill no longer required full attention; but, at the same time, the habit became attached and subject to the rigidity. To change any part of the habit would require a major transformation of thought.

This rigidity made new learning more difficult. In Interview X, the student described this habitual type of thinking was frustrating and time-consuming as well:

> And I do, I don't know if you noticed, but I do some pretty stupid mistakes when I make mistakes. I went in one day in the morning. I don't know how long I had worked on it the night before, but I would say at least 30 minutes, if not longer, on this problem. Could not get it right. I had gone over it and over it and could not get it right. Went in to [Mr. Sine], and we go over it. He checks it. I've got all my steps right. I divided wrong. We spent thirty minutes that morning and all I did was divided wrong. It made me so mad, because I spent all that time on a simple division problem.

People were simultaneously determined and freed by habitual thinking processes. These ideas could also be applicable to scientific thought or educational practice—any changes of ways of doing normal science [using Kuhn's (1970) terminology] required radical paradigm shifting.

The Holographic Mind

> In the heaven of Indra there is said to be a network of pearls so arranged that if you look at one you see all the others reflected in it. In the same way, each object in the world is not merely itself but involves every other object, and in fact is every other object.
>
> ♦ A Buddhist sutra as cited by Wilber, 1984, The Holographic Paradigm

Another student of Karl Lashley, Karl Pribram espoused a significant view of the mind as a hologram. Unable to explain the consolidation of new experiences and earlier learning as well as proven memory retention even with catastrophic injury, Pribram stumbled on the homology of a hologram. During a lecture symposium about knowing, he considered somewhere in Gestalt psychology was the answer. Perceptions, according to Gestalt theory, were isomorphic (something identical or similar in form, shape or structure) brain processes. He suddenly blurted out, "Maybe the world is a hologram" (Ferguson, 1982, p. 20). He later conferred with his son, a physicist, who suggested reading recent papers by David Bohm. Pribram felt Bohm, too, was suggesting a holographic world:

> What appears to be a stable, tangible, visible, audible world…is an illusion. It is dynamic and kaleidoscopic—not really "there." What we normally see is the explicit, or unfolded, order of things, rather like watching a movie. But there is an underlying order that is mother and father to this second-generation reality. He called the other order implicate, or enfolded. The enfolded order harbors our reality, much as the DNA in the nucleus of the cell harbors potential life and directs the nature of its unfolding (Ferguson in Wilbur, p. 21).

Pribram suggested the brain sent wave forms from visual recognition patterns, memories, and other parts of the brain. These wave forms converged in "dialectical patterns of interference and [one became] conscious" even when memory and "seeing" conflict (Hampden-Turner, p. 94). These wave forms operated at the quantum level as both a wave and a particle, electrically and chemically charged. Later research had shown Pribram to be correct.

To understand the homology of the hologram, further explanation was necessary. On most credit cards appeared a hologram placed for counterfeiting protection. This hologram stored a three-dimensional pattern of two laser beams of light crossing in interference. To visualize this interference, a person could think of dropping two pebbles into a dish of water. By quickly freezing the water, the pebbles formed two sets of concentric ripples. Even if the ice were broken into pieces as small as a square centimeter, the images were permanently encoded in every part of the ice (Hampden-Turner, pp. 96-97. See Figure 2).

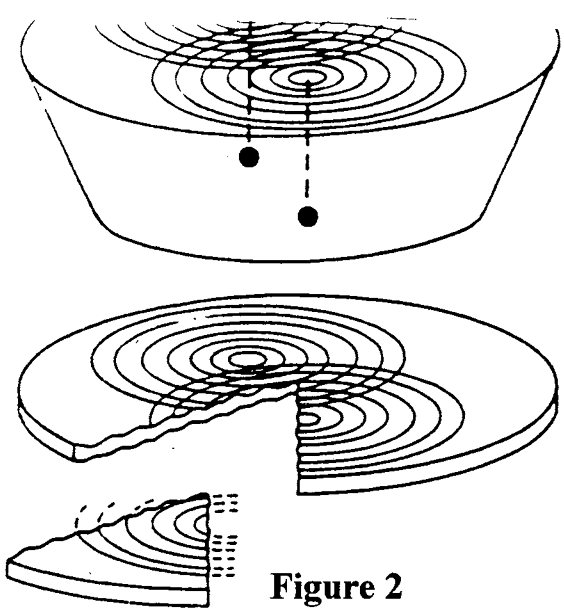


Figure 2

Actually, lasers created holograms by sending out light beams at one perfect frequency. When two laser beams intersect, they produced an interference pattern that could be recorded by an photographic plate (like the pebbles in the ice). At the same time, if an object were reflected by one of the beams, a recorded complex pattern of that reflection resulted.

This holographic image provided an explanation of the resistance of the brain to catastrophic injury. Rather than memories stored in one localized area as previous theories suggested, Pribram asserted memories were nonlocalized. Just like the ice, the coded ripples or codes memories were everywhere. Key concepts of quantum physics could be applied: the concept of wave/particle explaining the electrical and chemical processes of the brain and nonlocalization explaining stored memories and extended significantly Hebb's ideas of cell assemblies. Capra's ideas of mental space and Varela's phase locking also dovetailed into this view.

I would further suggest that nonlocalization had applications in learning, not just limited to the individual but also to the social interactions involved in learning. Student VI discussed how he and another student worked their mathematical problems together:

> We've known each other since the fourth grade and kind of grown up together. We kinda think alike when it comes to some things. Both think of the same things at the same time. Soemtimes we both make mistakes on the test and we both do exactly the same thing, but we'll do it a different way and come up with the same answer somehow. Kinda funny,...weird.

Was the student referencing nonlocality? I was not certain, but I felt the holographic image and nonlocalization had multiple possibilities. Both these terms possibly explained the infinite capacity of memory storage. One of the key characteristics of a hologram was its efficiency with no space-time dimension—"billions of bits of information [could] be stored in a tiny place…the image [was] stored everywhere…. (Ferguson, 1978, p. 19). Causal explanations were no longer valid. Instead, the brain performed complex calculations on the interpretation, not on the perception. "<u>These mathematical process have little common-sense relationship to the real world as we perceive it</u>" [(italics in original), Ferguson, 1978, p. 19]. Again, Pribram showed a commitment to theory prior to the facts. Current research and advances in technology in the neurosciences have proven many of his premises were valid. Hampden-Turner provided a relevant summary:

> Holographic storage is the most sophisticated, the most economic, and from an evolutionary standpoint, the 'fittest-to-survive of any method known to man….Pribram's holographic model is potentially the stuff of scientific revolution, resolving at a stroke the sterile dualisms of mind and matter….If he is right, then "immaterial" subjective experience alters brain structure, while that structure materially alters subjectivity and precise mathematical equations take the measure of both. He posits an open, intentional, cybernetic system of organism plus environment wherein consciousness is heightened by disparities between "feedback" and "feedforward" and mental breakdown is signalled by uncontrollable oscillations between the two with predictable delusions and hallucinations (pp. 96-97).

Hampden-Turner spoke of Pribram's work as a paradigm shift. (Interestingly, Pribram shared office space with Thomas Kuhn who, as discussed before, originated the term paradigm shift). Pribram's theory also foreshadowed chaos theory explaining the phenomena of feedback and oscillations and Edelmann's (1992) theory of neuronal group selection. These concepts were further explained throughout the remainder of this inquiry.

Not only did Pribram provide valuable suggestions for the organization of the brain, he also provided some important advice to all researchers:

> ...at some point in his life, every scientist must make a decision. He begins to be interested in his work and what his findings mean...Then he has to choose. If he starts to ask questions and tries to find answers, to understand what it all means, he will look foolish to his colleagues. On the other hand, he can give up the attempt to understand what it all means; he won't look foolish, and he'll learn more and more about less and less. You have to decide to have the courage to look foolish" (Ferguson, 1978, p. 19).

INTERLUDE 3

Buzzing, Blooming Confusion

We know as long as no one asks us to define it.

♦ William James (source unknown)

I had briefly recounted constructs prescient to current theories about the process of learning and brain functioning. At this point, I was attempting to construct my own definition of learning, but the maze of facts and possibilities seemed to strangle creative thought. I paused at this time and looked closely at the word <u>learning</u>. Learning, like theory, was one of those overused terms of educational jargon implying yet negating a general consensus of meaning. Learning was used interchangeably with a wide variety of terms (e.g., education, knowledge, cognition, information, training, and development.) The word choice was often indicative of the philosophical stance of the writer. What was my philosophical stance?

I decided three terms came closest to what I felt should be incorporated in my definition; all three were synergetic—learning, the act of knowing (borrowed from Ernst von Glasersfeld), and cognition. I looked to <u>Webster</u> (1989, 1997) to examine the etymology of these terms. First, learning came from the Old English meaning "last footprint" and hinted at more the sense of "coming to be able," "coming to realize." Contextually and currently, educators used the meaning of the external and directed action acquired by instruction or study, often with a significant other—a teacher, a book, a peer.

I felt the term learning meant more than current usage—something or someone leaving a lasting footprint or a fleeting image. Somewhere in my readings learning had been described as "the holy curiosity of children." That sacred quality needed to be included, but the only other term I could find was awareness. Language was limiting.

The second term, the act of knowing (or to know) implied a personal, conscious purpose—more involved with action. To know was from the Latin gnoscere to "come to know," defined as "perceiving directly, have direct cognition of, to recognize the nature of." The essence of "bringing forth the world," Maturana's words, seemed to fit. Philosophical stance was becoming clearer. "Coming to know" also reflected the possibility of a hidden order, deeply encoded structures, existing within systems of complexity and within the learner.

Webster (1989, 1997) suggested the words know and cognition were synonyms. Both terms shared the same etymology of gnoscere, but cognition implied values or judgment. Values colored cognition. An additional meaning was discovered by looking at cognate. Cognate had within its history the Latin gignere or "to beget" as in related by blood or descent. Did cognition then connote values within the individual and the universal collective past?

Moving from etymology to current writings, Capra's (1996) book, The Web of Life, framed final thoughts with three words "pattern, structure, and process" (pp. 158-159). Did these three words fit with the terms learning, the act of knowing and cognition? If so, how? Jerome Bruner (1996) saw the child as an epistemologist as well as a learner (p. 57). Epistemology was a requirement for new theory, according to Capra and Steindl-Rast (1991, p. xiii). How was this puzzle to fit in all the pieces? Pattern, structure, process—learning, the act of knowing, cognition—awareness, action, values—the external was now joined with the internal. The objective melded into the subjective.

The Definition of Learning

> The succession of scholars is like a single man endlessly learning.
>
> ♦ Pascal, 1668, Pensées

I inserted these reflective thoughts prior to the remaining discussion of this epistemic inquiry. I did so to involve actively the reader with the inductive and comparative processes of this inquiry. I now suggest to the reader consciously begin his or her own personal meaning of learning.

To assist this inductive process for both the reader and myself, I provided a sampling of general and specific definitions from a wide variety of sources in the psychological and educational fields. I did so without commentary. In an attempt to define learning, these definitions were presented not as a representative sample, but rather as a nonrandom selection to illustrate the diversity of current learning theories. It was important to note the dates and the word choice of the authors. (A special note: Because these definitions have been collected over the years from a wide variety of sources, they are not specifically referenced in the bibliography).

General sources:

> ...[learning is] the process by which changes in behavior result from experience or practice (The World Book Enyclopedia, 1976)

1: the act or experience of one that learns. 2. Knowledge or skill acquired by instruction or study. 3: modification of a behavioral tendency by experience (as exposure to conditioning) (Webster's Ninth New Collegiate Dictionary, 1989)

1: to get knowledge of (a subject) or skill in (an art, trade, etc.) by study, experience, instruction, etc. 2. to come to know. 3. to come to know how (Webster's New World College Dictionary, 1997)

Empirical definition:

a. accretion of specific units or connections (Charters, 1923)

b. a relatively permanent change in behavior which occurs as a function of practice (Saltz, 1971)

Educational and curriculum theorists:

a. reconstruction or reorganization of experience which adds to the meaning of experience, and which increases the ability to direct the course of subsequent experience (Dewey, 1916)

b. the means through which the human being gains power and becomes a controller of experiences and the environment (Sheperd & Ragan, 1982)

c. educational connoisseurship (Eisner, 1985)

d. how the mind works to process new information (Ausubel, 1986)

Theory of "classroom learning":

a process which occurs in stages on a continuum through time… [postulated as] (1) awareness and disequilibrium…(2) cognitive restructuring and integration…(3) schema development (Alton-Lee & Nuthall, 1990)

Behaviorism:

a. a relatively permanent change in a student's response potential based on experience and not the results of normal growth, maturation, motivation or temporarily induced states (Skinner, 1968)

b. a change in human disposition or capability, which can be retrained, and which is not simply ascribable to the process of growth (Gagne, 1977)

Humanistic philosophy:

more than the accumulation of facts….makes a difference—in the individual's behavior, in the course of action he chooses in the future, in his attitudes and in his personality (Rogers, 1969)

Social learning theory:

human behavior in terms of continuous reciprocal interaction between cognitive, behavioral and environmental influences (Bandura, 1971)

Ecological systems theory:

the cultural significance of the process and task in which mastery can be achieved (Bronfenbrenner, 1989)

Information processing:

Rather than getting side-tracked by attempting to distinguish between learning and development, I will use the more neutral term change, and it will be understood that the change is imposed by the system's own information-processing mechanisms (hence 'self-modification'). Note that while learning is usually defined—in one form or another—as 'the improvement of performance over time,' such directionality is not necessarily implied by change (Klahr, 1989)

Critical praxis:

a. conscientizacao…to perceive social, political, and economic contradictions, and to take action against the oppressive elements of reality (Friere, 1970)

b. [fostering the spirit of] wide awakeness (Green, 1978)

c. the promise of intellectual fellowship and radical openness (Hooks, 1994)

Constructivism (Piaget until 1975 – structuralist):

the interaction of a knowing subject and reality (i.e. from the action of subject on object)…depends on the subject's activity, on existing and newly composed structures, on a self-regulating mechanism and on the characteristics of the object (the environment, both social and physical) (cited in Beilin, 1989)

Cognizance/ possibility and necessity (Piaget 1987 – functionalist):

development of operational structure is the outcome of a more general evolution, and is not to be explained by operational development in and of itself. Operations require the synthesis of possibility and necessity. Possibility is provided by procedural freedom (flexibility); necessity is provided by self-bound compositions (cited in Beilin, 1989)

Neurophysiological:

After cell assemblies and phase sequences are developed,...subsequent learning is more cognitive. Adult learning, for example, often is characterized by insight and creativity, probably involves the rearrangement of phase sequences (Hebb, 1972)

Contextualism:

all higher psychological functions are united by one common characteristic, namely that they are mediated processes, i.e. that they incorporate in their structure, as the central and basic part of the process in general, the use of the sign as a basic means for directing and mastering the psychological process....thinking in complexes....and forming real concepts (Vygotsky, 1978)

Cognitive theory:

the act of deliberate study of a specific body of material, so that the material can be retrieved at will used with skill....involves purposeful remembering and skillful performance (Norman, 1982)

New cognitivism:

an active, goal-seeking process (van Rossum & Schenk, 1984)

Systems science:

closely associated with emergence, where connections are formed and new powerful wholes emerge out of disparate parts, otherwise termed the 'Eureka experience'" (Flood & Carson, 1988)

Creativity and the quantum theory:

constitutes evolutionary changes in the brain's substructure (Goaswami, 1988)

Multisource theory of learning:

creative reconceptualization of internal knowledge (Iran-Nejad, 1990)

Theory of neuronal group selection (TNGS)

results fromthe operation of neural linkages between global mappings and the value centers. [Learning] serves to connect categorization to behaviors having adaptive value under conditions of expectancy (Edelmann, 1992)

Radical constructivism:

knowledge is not passively received but built up by the cognizing subject; the function of cognition is adapative and serves the organization of the experiential world, not the discovery of the ontological reality (von Glasersfeld, 1995)

Deep ecology theory:

Cognition, the process of life, is inextricably linked to autopoiesis—the pattern of organziation of living system...Autopoiesis and cognition are two different aspect of the same phenomenon of life (Capra, 1996)

The Santiago theory:

Cognition is the activity involved in the self-generation and self-perpetuation of autopoietic networks. In other words, cognition is the very process of life (Maturana, 1970)

Enactivist model:

does not occur in individual minds or brains, but in the possibility for shared action...all cognition [cognition and learning used synonomously] exists in the interstices of a complex ecology of orgasmic relationality (Davis & Sumara, 1997)

CHAPTER 3 (CONTINUED)

CHAOS SCIENCE: A MULTIDISCIPLINARY OVERVIEW

A: A violent order is disorder: and
B. A great disorder is an order,
These two things are one.

♦ Wallace Stevens, 1942, "Connoisseur of Chaos"

What did stock markets, dripping faucets, the weather, human thoughts and learning processes have in common? They each provided opportunities to explore the world with a radically different perspective of chaos science—opportunities to value change, wholeness, and introduction into complexity. I had revisited significant ideas from the world of psychology. I had reviewed, albeit briefly, definitions of learning from a variety of schools of thought—all of which had marked the progression or evolution of ideas throughout the twentieth century. I believed chaos theory provided the juncture for these ideas to coalesce. Complexity theory and the neurosciences could then invent new ways of exploring learning. I believed four major publications had brought chaos theory to the general public and to the nonscientist: Order out of Chaos (Prigogine & Stengers, 1974); Chaos: Making a New Science (Gleick, 1987); Turbulent Mirrors (Briggs & Peat, 1989); and strangely, Jurassic Park (Crichton, 1990). I briefly reviewed these books and their major contributions, and then in the following sections provided more detailed information about these terms and processes. Thus, the organization of this section reflected the methodology and order of my own multivocal research.

The first book—written by the Nobel prize-winner, Ilya Prigogine and his co-author, Isabell Stengers—provided a new systems theory of life and applied chaos theory and dissipative structures to biology. Important to this inquiry of learning processes was Prigogine's concept of dissipative structures. Dissipative structures, or entropy-rich environments far from equilibrium, facilitated rather than obstructed self-organization. Like the ancient mythical tradition, chaos became the "precursor and partner" to order (Hayles, 1990. p. 9).

The second book, Chaos: Making a New Science (1987) by James Gleick, presented the historical overview of the multidisciplinary study of chaos to the non-scientist. He introduced the unique terminology of chaos; but he also combined the scientific with the personal, as he delineated the struggles and emotional conflicts of the scientists discovering the controversial theory during a pre-paradigmatic period.

Briggs and Peat (1989) simplified the major constructs of the two earlier books with an illustrated guide (using figures of the Yellow Emperor and Alice in Wonderland) and presented chaos as the science of wholeness. And, most creatively, the best-selling novel by Michael Crichton (1990, 1993 and also a major film released June, 1993 by the same name) Jurassic Park made chaos terminology of fractal curves and iterations household terms. Crichton fictionalized applications (and misapplications) of chaos mathematics.

Chaos Bound

Without dimension, where length, breadth, and height,
And time and place are lost; where eldest night
And chaos; ancestors of nature, hold Eternal anarchy.

- John Milton, (1608-1674), Paradise Lost

Far from the clones of carnivorous dinosaurs of Jurassic Park, I also presented a fifth book by N. Katherine Hayles (1990), Chaos Bound, which illustrated more specific rather than public interest. Hayles joined chaos science with contemporary literary criticism; and her educational background reflected the juxtaposition. Her undergraduate work was in chemistry: her advanced studies were in English. Although not the first educator to connect chaos with education (see e.g., Doll, 1989), N. Katherine Hayles perhaps represented a more developed overview of chaos science with educational concerns.

She asserted the context and the methodology of educational and literary research must change because of prevailing cultural influences. She argued that within the present culture was an "archipelago of chaos" (p. 3). She supported her thesis with an explanation of field concept based on cultural influences and isomorphic assumptions similar to the social paradigm (Capra, 1982, 1983, 1996; Capra and Steindl-Rast, 1991; Kuhn, 1970): "Different disciplines are drawn to similar problems because the concerns underlying them are highly charged within a prevailing context" (p. xi).

Not only was she advocating a new paradigm; she insisted on using new methodologies. Recognizing the participatory universe, she asserted the researcher was in and a part of the field; no exterior, objective viewpoint of the traditional was possible. More importantly, the observer was "caught in and constituted through the very interactions that one is trying to describe" (p. xii).

Hayles began her explanation of chaos with a disclaimer. The terms chaos theory or the science of chaos was usually associated with the "dilettante rather than the expert" (pp. 8-9). Nonlinear dynamics, dynamical systems theory or dynamical system methods were preferred in the scientific community. However, she (and I concurred) used chaos theory because the "rich tradition of mythic and literary significance" provided the framework of a "highly charged signifier" of interdisciplinary approaches: "...the name [chaos] is important, for in its multiple meanings it serves as a crossroads at which diverse paths within the culture meet" (p. 9).

Although I considered her applications of chaos science weak, Hayles' explanation of chaos science was excellent. She presented a compelling argument that chaos science had two distinctive branches or emphases. The first one was order-out-of-chaos popularized by Prigogine and other European intellectuals. This branch was known "for its willingness to extrapolate beyond experimental results to philosophical implications" (p. 10).

The second branch emphasized the strange attractor and "the hidden order that exists within chaotic systems" (p. 9). In contrast to true randomness that revealed no patterns, strange attractors were bounded to a phase space and traced complex patterns and deep structures of order. She contended this branch has been under-theorized with practitioners emphasizing the practical rather than the theoretical. She summarized the differences of the two branches: "In brief, the order-out-of-chaos has more philosophy than results; the strange attractor branch more results than philosophy" (p. 10).

FRACTAL DETAIL OF CHAOS

For want of a nail, the shoe was lost;
For want of shoe, the horse was lost;
For want of a horse, the rider was lost;
For want of a rider, the battle was lost;
For want of a battle, the kingdom was lost.

♦ Old English folklore

"It's like you have been on the trail for some research, and you finally found this. It's like great! And I know how I'm going to use it somewhere else." Although describing learning, not fractals, Student XIII shared my same feelings. When I viewed the images of fractal patterning, the elegance and possibilities seemed endless. The most common references to chaos science included these elegant symmetries (see Appendix f for images of fractal clusters, the Lorenz attractor, the Koch curve, and the Mandlebrot set). I still believed this symmetry is deep within the actual physical structures of the neuronal system, perhaps at the quantum level.

However, I felt the most important contribution of chaos to this epistemic inquiry was the discovery of dissipative structures. Prigogine, in his most current book, <u>The End of Certainty</u> (1996) offered a clear picture of dissipative structures:

> A nonequilibrium system may evolve spontaneously to a state of <u>increased complexity.</u> The ordering we observe is the outcome of irreversible processes, and could not be achieved at equilibrium....Beyond the bifurcation point, a set of new phenomena arises; we may have oscillating chemical reactions, nonequilibrium spatial structures, or chemical waves. We have given the name <u>dissipative structures</u> to these spatiotemporal organizations (pp. 64-66; see Appendix G for the Belousov-Zhabotinskii reaction which depicted oscillating chemical reactions of dissapative structures).

From his biological stance, Prigogine introduced an entire new vocabulary to the discussion of learning. He stated the birth of the science of complexity (he used complexity more than chaos) began in the early nineteenth century with Fourier's mathematics. At that point, the science of thermodynamics began; and from that time on, mathematics, physics, and Newtonian science ceased to be synonymous terms. He suggested Carnot's (1824) original formulation of the second law of thermodynamics directly led to the first quantitative expression of irreversibility (p. 111).

Out of these two discoveries, two more questions emerged. What is the relationship of disorder? What is the meaning of time? In traditional science, nature followed a static, linear path of reversibility. Yet chaos theory found nature favoring two pathways, coexisting yet paradoxical—reversibility and irreversibility. Prigogine and Stengers felt the concept of entropy illustrated the dichotomy of these terms. Within the second law, entropy increased as it moved from order to disorder; but in biological terms, systems evolved from the simple to the complex. Often called the "arrow of time," entropy increased in the direction of the future, not of the past. Prigogine and Stengers (1984) stated emphatically: "Increasing entropy corresponds to the <u>spontaneous evolution</u> of the system. Entropy thus becomes an 'indicator of evolution,' or an 'arrow of time,'..."(p. 119). Within irreversibility were three basic elements—intrinsic irreversibility→ intrinsic randomness→ instability. Irreversibility was the strongest property because it implied the other terms (p. 276).

Student XIV came the closest to describing the evolution of thought: "discussing the teacher's explanation]... he does a real indepth job, so indepth that 20 minutes ago I had a different question and now I have lots more. I guess that's good in a way that he opens up your mind to be able to question a lot of things."

Another example could provide an explanation of entropy of a physical state. In contrast to the student and teacher, this example was an isolated physical state. Based on the theory isolated systems moved into a state of increasing disorder, a swimming pool was divided by a fixed barrier. One half of the pool was filled with water, and the other half was filled with ink. When the barrier was removed, the random motion of molecules mixed the water and ink. This mixing never reversed itself, and time became a one-way street or arrow of time.

From this application to living systems, Prigogine and Stengers reformulated disparate ideas to connect entropy, disorder and irreversibility within macrosystems. They discovered quantum behavior such as the wave/particle paradox was also applicable in the macrosystem (p. 179). Randomness was essential. Systems fluctuated around an attractor state, where a variety of events compensated each other statistically. However, controlled by initial conditions, a dynamic macrosystem and its natural processes could either increase entropy leading to a thermodynamic equilibrium or to maximum entropy. Thus if the direction was towards entropy, a symmetry-breaking principle then applied: the second law as a symmetry-breaking selection principle → probabilistic interpretation → irreversibility as increase of disorder (p. 297). With this reformulation of the second law and introducing the selection principle, Prigogine was able to unite dynamics and thermodynamics as fundamentally important in an evolutionary context.

First, Prigogine (1996) emphasized the constructive role of irreversibility in far-from-equilibrium instances. He strongly asserted it was "precisely through irreversible processes associated with the arrow of time that nature achieves its most delicate and complex structures" (p. 26). Secondly, he focused on the important juncture of nonequilibrium. The disorderly behavior was the creative process, not the assimilation or accommodation back into balance. Prigogine named the self-organizing structures dissipative because the maintenance of organizational complexity was only possible by dissipating the high entropy energy produced back into the environment thus creating irreversible patterns. Strange attractors served as mixers; they created unpredictability and raised entropy. Entropy created information where none existed before: "A nonequilibrium system may evolve spontaneously to a state of <u>increased complexity</u>. The ordering observed was the outcome of irreversible process and could not be achieved at equilibrium" (Prigogine, 1996, p. 64).

THE EMERGING

> On its own, a neuron firing has no meaning, no symbolic quality whatsoever....It is a level shift as drastic as that between molecules and gases that take place when thought emerges from billions of in-themselves meaningless neural firings.
>
> ♦ Hofstadter, 1985, <u>Godel, Escher, Bach</u>

Although used in a different context, Dobson and Dobson (1990) summarized elements of chaos theory: "[The] behavior of an open system is a reflection of that system's interactions with other systems in its surroundings....[That behavior] does not lend itself as much to an act of translation as it does to transformation...a process, constantly unfolding" (unpublished manuscript).

From an unfolding process of disorder and randomness towards an order of greater complexity, biological structures were thus transformed. Looking again at Prigogine's model, slight fluctuations or perturbations were continually occurring within dynamic systems. When the density of random perturbations were no longer at near equilibrium and averaging out could not occur with the subsystem, the macroscopic response became a bifurcation.

Alvin Toffler summarized the concept of fluctuations in the subsystems and the bifurcation point:

> ...a single fluctuation or combination of them may become so powerful, as a result of positive feedback, that it shatters the preexisting organization. At this...singular moment or bifurcation point—it is inherently impossible to determine in advance which direction change will take: whether the system will disintegrate into "chaos" or leap to a new, more differentiated, higher level of "order" [dissipative structure]....Order and organization can actually arise "spontaneously" out of disorder and chaos through a process of self-organization (forward in Prigogine and Stengers, pp.xi-xxvi).

"Bi" implying two pathways created probability but not predictability. The system could "disintegrate into chaos" or "leap to a new order." In this context, the barrier of entropy had already been broken. The only two choices the system could make at this point was either total chaos and disintegration or a jumping into a totally new and higher order which involved limitless possibilities.

The simplest form of bifurcation was named the "pitchfork bifurcation" (see Appendix E). Prigogine called bifurcations a source of symmetry breaking. Homogeneity of time or space or both were broken. Usually, once a point of bifurcation was reached, a successive pattern of bifurcations occur (see Appendix E): "the temporal description of such systems involves both deterministic processes (between bifurcations) and probabilistic processes (in the choice of the branches). There is also a historical dimension involved" (Prigogine, 1996, pp. 69-70). Although at this point, Prigogine did not explain the historical dimension, I suggest, for biological systems it involved evolutionary processes involving both ontological and phylogenetic structures.

Gleick (1987) used an analogy of a stretched rope. Suppose one could not determine the tensility of the rope which was continually stretched to search for the ultimate point. At the ultimate or bifurcation point, the rope broke and immediately assumed new properties as two more complex patterns. However, I would argue that this analogy, although helpful, implied that there was a splitting and relatively no structural change except for length. In Prigogine's context, I believe, when the rope became two, both ropes were qualitatively different (e.g., one became a metal cable and the other a fiberglass ski rope).

Randomness locked into these patterns or parameters. The parameters described the change of systems over time. Involved within these parameters was the sensitivity to initial conditions. The transformation was in the process of becoming or emerging, a process of disorder for no pattern was ever exactly replicated (see the Lorenz attractor, Appendix F). Gleick (1987) emphasized that the disorderly chaotic dynamics was a creative process: "[The creative process] generated complexity: richly organized patterns, sometimes stable and sometimes unstable, sometimes finite and sometimes infinite" (p 43).

However, it was important to clarify I felt not all disequilibrium meant creative thought. Sometimes the human response to the disorder or chaos was high frustration and giving up. Student XIV discussed the variety of emotions involved in the learning process. Even the explanation denoted frustration. There was no way the student felt she could anticipate the outcome—success or frustration:

> I will feel very relieved [reference not clear] because right now I'm having problems with [trig]. Like I said sometimes I do it so mechanically I don't feel....Sometimes I don't feel anything unless I have had trouble with it and then I understand. Like physics, the other night I just worked for hours on this one problem. When I finally got it, I was so happy because I didn't have to call anyone yet....It makes you feel good but if I can't get it, I just kind of put it off and tomorrow I go to class and ask. Sometimes I'm frustrated....

In addition, there existed another inherent paradox within chaos of determinism and randomness. Because of the mathematical formulas involved in chaos theory, many scientific researchers as well as educators emphasized the term <u>deterministic chaos</u>. For many persons, the term "deterministic" immediately had mechanistic connotations; but if the term was examined carefully within this context, cause and effect was discounted. Like this student, I abandoned the deterministic description associated with the dynamics of learning (see Prigogine, 1996, p. 68-69 for a detailed explanation). The system chose the path or the "branch" available when responding to the process far from equilibrium. Nothing in any macroscopic equation determined which branch would be taken introducing an "irreducible probabilistic element" (p. 69).

This specific conjecture is where I believe most educational theorists erred. They either looked at the emphasis on sensitivity to initial conditions, or the mathematical iterations, or the randomness but most often not within the same structure. Without understanding the inherent paradox of order and disorder, randomness and determinism, using chaos terminology only substantiated their own personal biases. Gleick stated this misunderstanding yet another way: "...locally unpredictable, globally staple. Real dynamical systems played by a more complicated set of rules than anyone had imagined" (pp.48-49).

Gleick also asserted even biologists had previously overlooked bifurcation for two reasons. One, they lacked the mathematical sophistication; and two, they simply lacked the motivation to explore disorderly behavior (p. 77). Yet within chaos science appeared the feeling of flow, "shape plus change, motion plus form...similarities across scales and the recursive power of flows within flows" (p. 195). Gleick found no scientific language to express the constructs, so he also looked to the poet: "The flecked river/ which kept flowing and never the same way twice, flowing/ Through many places, as if it stood still in one...(Wallace Stevens as cited in Gleick, p. 196.)

Within entropy, within learning was the feeling of change and of possibility. Student XIV interpreted learning as the possibility for good:

> I think it's something like...someone gives you a concept—no matter whether it's academic or in speech or in life or something—and you take it and do whatever you want with it. You can expand on it, or take it like they taught you (a lot of people say it's how you interpret things) and to be able to contribute it back into your environment. If you were able to do something good with it or teach someone else or use what I learned to apply something that benefits people....

THE EMERGENT

> The notion of structure is comprised of three key ideas: the idea of wholeness; the idea of transformation; and the idea of self-regulation.
>
> ♦ Jean Piaget (source unknown)

Computers and technology now provided the means for more sophisticated mathematics. Considering each human cell had approximately 10,000 genes creating intricate patterns of interactions, biologists no longer had the luxury not to explore complexity. Once dissipative structures were understood, self-organization could be examined. Prigogine (1996) referred to a recent report given to the European Communities: "Self-organizing systems allow adaptation to the prevailing environment....The superiority of self-organizing systems is illustrated by biological systems where complex products can be formed with unsurpassed accuracy, efficiency and speed" (pp. 71-72).

Part of the explanation of the accuracy and speed of self-organizing systems was within the concept of feedback. Cybernetics and systems theory introduced the idea of negative feedback which distinguished between linearity and nonlinearity. (Nonlinearity equations had terms repeatedly multiplied by themselves.) Negative feedback was most easily understood by looking a furnace and a thermostat (Briggs & Peat, p. 25). The action of the furnace was determined by the thermostat, but the action of the thermostat was determined by the furnace.

By the 1950's, discussions of positive feedback occurred. (The screeching of a microphone was a simple example.) The terms "negative and positive" were not to be considered as value statements, but rather distinctions that one type regulated and the other amplified. Again, the inherent tension between order and chaos was described (Briggs & Peat, p. 26). In Interview V, the student described amplification within the social context when she was struggling with learning. She even used the term "amplifies."

> Uh, well, when you learn, you've been struggling with something a long time and you finally learn it, you just get really, feel really, really good. And if you learn something quick, you feel good but not as great as before because you didn't have to struggle with it. [Describe the struggle.]. Well, just the feeling of helplessness. I guess you could say, of not being able to learn it. And I think it really amplifies that feeling if everyone around you <u>does</u> understand it. You feel kind of left out or like you're just not getting it [laughs].

Not only was there tension between order and chaos, but tension was present between stabilization and creation. Stuart Kauffman, a theoretical biologist of the Santa Fe Institute, contended researchers had to look beyond Darwin's theory of random mutations and natural selection. Recognizing the great diversity of living organisms today, he felt the answer was not random mutations but rather the "preference of complex systems to spontaneously organize themselves into persistent patterns of activity that work[ed]." Kauffman simply stated: "Darwin did not know about self-organization" (as cited in Casti, 1994, p. 267).

Systems typically settled into a small number of periodic attractors. However, it was, according to Kauffman, through the "subtle interplay of stable and unstable attractors—cooperation and competition—that patterns of change and periods of stasis [could] slowly evolve" (p. 268). Even at the quantum level, the spontaneous organization worked toward a more viable structure. The conclusion was nature practiced a universal tendency towards spontaneous organization (Rocha, 1998).

In his discussion of self-organization, Rocha separated chaotic and disordered systems. Chaotic explanations did not go far enough because of their dependence on initial conditions rather than with the interaction of relevant events in the environment. Point attractors and limit cycles explained in chaos science did not allow enough behavioral change for the needed diversity. Rocha clearly espoused an interest in artificial intelligence; however, his suggestion of a hybrid theory of structural change and the correspondence with an ordered interaction with the environment was relevant.

Holland (1998) also questioned the emphasis of chaos on remote initial conditions that could never be assessed. He used the example of meteorology to counter chaos' application. (Strangely, meteorology and Lorenz's butterfly effect had been credited with beginning chaos' explanatory applications). Holland argued meteorology started again daily based on current information bringing the "state of the model into agreement with what has actually occurred," and "[under] this regime chaos theory has little relevance" (p. 44). He referred back to Donald Hebb's seminal work now confirmed through sophisticated techniques in tracing biochemical activity in the brain (p. 85). Holland provided a helpful explanation of the workings of the neural net. However, I believe he failed to describe the process of emergence.

Capra (1996) provided the most complete synthesis of emergence. He compared earlier models of self-organization to later models that included the creation of new structures as well as new models in the self-organizing process (p. 85). He delineated three important differences between the early discussions and later models. First, early models emphasized the richness and variety of available structures, but did not include the processes of creativity, development, or evolution. In contrast, the more current research in these processes emphasized the creation of novel structures.

Secondly, these structures occurred only when the systems were far from equilibrium, a fact I had previously discussed. Thirdly, common to all newer models, according to Capra, was the "nonlinear interconnectedness of the system's components" which could be described mathematically in nonlinear equations (p. 85). By stating these three differences, I was giving credence to the mathematical component; however, it was beyond this epistemic inquiry (and admittedly, beyond my personal expertise), to discuss the ramifications of the mathematics. Capra provided a succinct summary of these three important characteristics of self-organization: "...self-organization is the spontaneous emergence of new structures and new forms of behavior in open systems far from equilibrium, characterized by internal feedback loops and described mathematically by nonlinear equations"(p. 85).

Student XV was able to describe self-organization at a interpersonal and inner personal level by relating an incident in a class where other students were giving her a very hard time. She was ready to give up:

> And so, I went up to ask the teacher, and he said, "You know how to do this."

"But I haven't done this."

"Just go back. You know how to do this."

"But those guys. They keep giving me a hard time."

"Don't listen to them. You know more about it than they do. You can do it."

I went back, and I did it, and I was so proud of myself.

CONTEXTS FOR LIVING

> … to regress permanently to earlier patterns is to die within ourselves….The necessity to find ever-new solutions to the contradictions in his existence, to find ever-higher forms of unity with nature, his fellow men and himself, is the source of all psychic forces which motivate man, all of his passion, affects and anxieties.
>
> ♦ Eric Fromm, 1990 (reissue), The Sane Society

In the discussion of the mind as a holograph, the laser was described in making a hologram. Now I turned to the discovery of laser itself as another example of self-organization. LASER was an acronym for light amplification through stimulated emission of radiation. Hermann Haken, a physicist from Germany, in his research on lasers found many similarities to other systems far from equilibrium and speculated even the laser was an example of self-organization. He coined the term synergetic to describe the need of a new discipline concerned with the processes of self-organization. Referring back to Koestler's principle of ripeness, Haken discovered an example of dissipative structures in yet another field of study. Capra (1996) cited a tribute given to Haken:

> …the laser can be seen at the crossroads between quantum and classical physics, between equilibrium and non-equilibrium phenomena, between phase transitions and self-organization, and between regular and chaotic

dynamics. At the same time, it is a system which we understand both on the microscopic quantum mechanical and on the macroscopic classical level (R. Graham, 1987 in R. Graham & A. Wunderlin (Eds.), Lasers and Synergetics as cited in Capra, pp. 91-92).

Capra also credited a third person instrumental in the explanation of self-organization. Manfred Eigen, a Nobel Laureate in chemistry, was questioning the origin of life. He hypothesized life on earth might have originated with a process of "progressive organization in chemical systems far from equilibrium, involving 'hypercycles' of multiple feedback loops" (p. 92). Eigen termed this "prebiological evolutionary process" as "molecular self-organization," now called catalytic cycles. The most common examples of catalytic cycles were human enzymes. Again, the use of homology seemed relevant.

Rather than looking at the open system construct of Prigogine and dissipative structures, Eigen formulated biochemical systems formed closed loops far from equilibrium. Similar to the chemical clocks that Prigogine studied, Eigen's catalytic cycles interlinked with each other to form hypercycles. Eigen also discovered hypercycles were capable of self-replication and even correction of replication errors (Capra, p. 94). These hypercycles experienced multiple levels of instabilities and emerged with increasing levels of complexity and diversity.

Integrating the discoveries of dissipative structures (open systems), lasers and hypercycles (closed systems), the famous Chilean neuroscientist and philosopher, Humberto Maturana looked not for the origin of life but rather for the answer to "what is the organization of life?" He began formulating ideas on cognition as an extended biological phenomenon. Maturana stated: "The nervous system operates as a closed network of interactions, in which every change of the interactive relations between certain components always results in a change of the interactive relations of the same or other components" (Maturana, 1970, "Biology of Cognition" reprinted in H. Maturana & F. Varela, 1980, Autopoiesis and Cognition, Dordrecht, Holland: D. Reidel as cited in Capra, p. 96).

Maturana identified cognition – and based on prior discussion, I asserted learning—as the process of life itself: "Living systems are cognitive systems, and living as a process is a process of cognition" (Maturana, 1970, as cited in Capra, p. 97). Francisco Varela later joined Maturana, and their findings added yet another dimension to this epistemic inquiry. They coined the word autopoiesis to describe the biologically complex circular organization of cognition. The formal definition of autopoiesis (Greek auto meaning self and poiesis meaning creation, production) follows:

> An autopoietic system is organized (defined as a unity) as a network of processes of production (transformation and destruction) of components that produce the components that (1) through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them; and (2) constitute it ...as a concrete unity in the space in which they [the components] exist by specifying the topological domain of its realization as such a network (Varela, 1979, Principles of Biological Autonomy, New York: Elsevier as cited in Whitaker, 1996).

Maturana and Varela took this complicated idea of autopoiesis and extended their findings into social systems theory, communication, and the enactive tradition of cognitive science (Varela, Thompson, and Rosch, 1991, The Embodied Mind: Cognitive Science and Human Experience, Cambridge, MA: MIT Press as cited in Whitaker, 1996).

In summary of Maturana and Varela, three important ideas emerged: (1) the circular organization of the nervous system was the basis of all living systems; (2) a radical new understanding of cognition was defined (3) a new biologically based epistemology redefined reality: "The activities of nerve cells do not reflect an environment independent of the living organism and hence do not allow for the construction of an absolutely existing external world" (Maturana, 1970, as cited in Capra, p. 97).

Whitaker (1996) also provided a helpful comparison of three traditions of cognitive science—cognitivism, emergence and enactive (see Appendix H for this comparative analysis). The cognitivism tradition was exemplified by the information theorists. If the reader could visualize an imaginary dotted line between the traditions of emergence and enactive, I believed my epistemic inquiry would be there. It would be offered as a merging, but not a synthesis, of the two traditions. The dotted line also represented my reluctance to view any theory or approach as an either/or proposition.

BOOTSTRAPPING PHYSICS

> Science...means unresting endeavor and continually progressing development toward an aim which the poetic intuition may apprehend, but which the intellect can never fully grasp.
>
> ♦ Max Planck, 1936, The Philosophy of Physics

About ten years before Maturana and Varela began publishing their autopoietic theory, a physicist named Geoffrey Chew looked at the interactions of subatomic particles in quantum theory. Interacting particles, which he called "hadrons," formed a network of interactions which also displayed circular feedback with each particle involved in the generation of new particles which in turn generated it (Capra, 1996, p. 99). Zukav (1979) suggested that Chew's theory may be the "physical analog to the Buddhist theory of interdependent originations" (p. 239). According to Mahayan Buddhism, the appearance of physical reality was based upon the interdependence of all things (p. 239). Because quantum theory dealt with probability rather than prediction, chance determined what combinations of interdependence occurred.

Bootstrapping could also be a homology for this inquiry. Progressing in this epistemic inquiry, the commonality was the interlocking connections within all the disparate ideas. Capra (1991) quoted one of Chew's early papers: "Somebody who is able to view different models without prejudice, without saying that one is more fundamental than the other, is automatically a bootstrapper."(p. 140).

Maturana and Varela maintained the concept of autopoiesis was inclusive in defining living organisms and cognition. But Capra (1996) employing the homology of bootstrapping insisted that the descriptions of Eigen and Maturana-Varela were needed for organizational understanding of neural networks and Prigogine and Haken were needed for structural understanding if a coherent theory were to be found (p. 99).

From these key scientists, the understanding of the brain and the process of the mind had grown exponentially. My summary findings for the learning process suggested the biological neural processes were (a) self-organizing open dissipative structures <u>and</u> self-organizing closed neural systems of cognition (b) self-referring interlocking networks through continual circularity feedback (c) continually self-creating new structural relationships.

Referring back to Capra and Steindl-Rast's (1991) insistence epistemology must be an integral part of any scientific theory (p. xiii), Maturana and Varela's scientific theory fulfilled this requirement through their focus on epistemology. I agreed with their epistemological premises and found this construct consistent with other findings within the inquiry. By interpreting interlocking patterns of perceptions, I was engaged in creating and re-creating autonomous views of reality —unique, viable, ever-changing.

ON THE MATTER OF THE MIND BRAIN

> The pillars of nature's temple are live
> and sometimes yield perplexing messages;
> forests of symbols between us and the shrine
> remark our passage with accustomed eyes.
> Like long-held echoes, blending somewhere else
> into one deep and shadowy unison
> as limitless a darkness and as day,
> the sounds, the scents, the colors correspond.
>
> ♦ Baudelaire, 1857, "Correspondences"

Pattern, Structure, Process

To continue the bootstrapping process, the actual structure and organization of the brain should be examined. Most educators did not seriously consider the physical components of the brain with learning, often discarding or ignoring the biological components. Current trends in educational research tended to focus on oversimplification of the biological. This last section of the multivocal research was offered to visualize the abstractions of the important biological theoretical findings. Key to my findings was Edelmann's (1992) On the Matter of the Mind, but other authors were also considered. The triad of pattern, structure, and process helped organize the discussion.

Pattern

First, considering pattern, Whitsel and Kelley (1988) accepted the necessity of looking at the neural network in toto or in gestalt terms, but admitted neuroelectrical studies were most commonly concerned with only a few neurons. To find the gestalt, they used complex mathematical analysis; and they defined steady states or near equilibrium. Up to this point, this study had looked at the far-from equilibrium states of dissipative structures. They proposed steady or near-equilibrium states were simply memories rather than points of creative or higher level learning (p. 105). This simple explanation of memory fit well within the other findings and alleviated attempting to differentiate between learning and memory.

The difference between learning and memorization was discussed by many of the students. Feelings were also closely related to the concept of learning creating a total pattern of experience. In their view, memorization was not the same as learning. Student VII, a white male, discussed these feelings:

> Uh, if you learn something, personal pride. Feel good about yourself because you know that you have learned something. When you are in a class, and you're trying to learn everything, and you are and actually going below the surface, you feel good about it. When you take a test, like a memorization test, there's no good feeling in that. You just memorized stuff.

Also included in the patterning component was the fractal, surprisingly described very eloquently within this very technical and mathematical article. Whitsel and Kelly (1988) offered a rich description in the midst of complex mathematics: "[The] headmass becomes an exchanged loom where millions of flashing shuttles weave a dissolving pattern, always a meaningful pattern though never an abiding one; a shifting harmony of subpatterns" (C. Sherrington, 1946, Man and his Nature, Cambridge, MA: Cambridge University 1946 as cited in Whitsel and Kelly, pp. 105-106). Rather than William James' "buzzing, blooming confusion," the brain's activity could be described as multiple fractals recreating similar but ever diminishing patterns of scale.

Often only computer simulations provided the visual graphing for the complexities and abstractions of fractal imagery. But Whitsel and Kelly asserted an elaborate connectivity demonstrated a range of dynamic, coordinated unpredictable behavior within the neural networks. Leon Cooper (1988) described the patterning as a "process of the persistence to remember" much more like a hologram rather than a two-dimensional photograph (p. 171). This statement referred back to Pribram's holographic image of the brain. Varela, Thompson and Rosch (1991) described the brain as a highly cooperative system with dense interactions with all component parts: "As a result the entire system acquires an internal coherence in intricate patterns even if we cannot say exactly how this occurs" (p. 94).

Structure

This rich description now became even more complex. According to the authors, Maturana, Mpoduzis and Letelier (1995), and to extend the discussion of autopoietic dynamics, the organization of a system was realized in its structure. If the organization of the system was conserved when structure changed, the system remained the same; if the organization was not conserved, the system disintegrated or disappeared. The structural changes were a direct result of internal dynamics. These three authors named the external elements creating structural change perturbations; those external elements causing disintegration were named destructive interactions. The system was in constant flux and continuous structural change as it interacted with the environment. As a living system and the environment interacted, they triggered in each other structural change; and this process was repeated recursively. Fluidity and flexibility allowed these recursions. Capra, in his explanation of Maturana's theories, connected cognition to structural coupling and called the structural changes a distributive phenomenon:

> The entire network responds to a selected disturbance by rearranging its patterns of connectivity...Different organisms change differently, and over time, each organism forms its unique, individual pathway of structural change in the process of development. Since these structural changes are acts of cognition, development is always associated with learning. In fact, development and learning are two sides of the same coin. Both are expressions of structural change (p. 268).

In a closed system, structural change through self-organization was key in autopoiesis. Prigogine's self-organization of dissipating structures created the spontaneous emergence of new structures in open systems far from equilibrium. I believe both types of structural changes occurred as a direct result of a person's creative thought or learning at the system or macrolevel and at the quantum or microlevel.

Process

Maturana and Valera seemed to separate their discussion of autopoiesis into structure and process. Autopoiesis applied to all life. Language separated human beings with other life. However, Gerald Edelman (1992) discussed only the human system. Within this system, the physical descriptions of the neural network were not considered structures as much as part of the overall process of mind. Maturana-Valera and Edelman endorsed two very divergent philosophies. Never citing Maturana nor autopoiesis, Edelman (1992) also felt structure, interconnection, and process were key components to his theory.

Edelman (992) began his discussion with a historical background and psychological theories. He emphasized William James' view that mind was a process beyond physical structure of the brain. Edelman believed the biological organization of the brain gave "rise to mental processes" (p. 7). These mental processes originated from an "enormously intricate brain system at many different levels of organization" including molecular, cellular, organismic and transorganismic levels interacting and communicating with each other (p. 7). (From this point in this inquiry, I will used two terms to differentiate process and structure. The term <u>brain</u> will refer to specific physical structures as well as overall organization; the term <u>mind brain</u> will refer to the interconnected multilevels of process. Various authors have used the term mind brain discussing similar theories, e.g., Bruner, 1983; Capra, 1996).

To understand Edelman's argument, specifics of the organization of this neural network should be presented. Edelman first stated the physical matter of the brain was not at all special, but what was special was the organization. Humans as complex organisms had about 200 different types of cells, of which the most specialized was the neuron. The neuron was unusual because of its varied shape, its electrical and chemical functions, and its connectivity (Edelman, 1992, p. 16). The higher functions such as speech, thought, complex movement and music were central to the cerebral cortex, a "corrugated mantle that covers the dome and the sides of [the] brain" that if spread out would be about the size of a table napkin and about as thick (p. 17). There were about ten billion neurons in that cortex with approximately one million billion connections called synapses. However, this astronomical number did not include the various combinations of connections. "The brain is the most complicated material object in the known universe" (p. 17).

The variety of shapes of neurons determined part of the linkage through a complex mapping patterning connected with each other through fibers. Again, the numbers were beyond comprehension (e.g., The major fiber bundle connecting right/left brain hemispheres alone contained about 200 million fibers).

There were also general organizing principles because the arrangement of the brain was "staggering in its intricacy and diversity" (p. 21). It was made up of sheets with topographic characteristics with maps mapping to each other. The tissue itself responded chemically and electrically in a three-dimensional space. (I hypothesized if the quantum level were considered, the dimensions could be even greater). Because the principles were epigenetic, there were no prespecified connections or hard-wiring as some theorists suggested. The numbers and variations were simply too great (pp. 23-25). From individual to individual, the connectivity was similar but not identical. To add further complexity dimensions, the neurons sent "branches of their axon out in diverging arbors that overlap with those of other neurons, and the same is true of processes [note the word processes] called dendrites on recipient neurons" (p. 25). In summary, the mind brain was an example of a self-organizing system par excellence. Previous changes altered successive changes self-generated in feedback loops.

The treelike arbors that overlapped and interacted in a signaling process were not like the historical metaphors of computer or telephone exchange but rather "more like the vast aggregate of interactive events in a jungle" (p. 69). Within this jungle, according to Edelman (1992), evolution factors "work by selection, not instruction [with] no final cause, no teleology, no purpose guiding the overall process" (p. 74). Another controversial statement was no direct information was involved in the formation of the mind brain at the genetic level; neither did the mind brain receive direct information from the external world. The mind brain did not work like the computer with a one-to-one informational input. Rather the workings were selective recognition.

Student XV described this jungle within the brain: "...and all of a sudden the answer comes out of nowhere and I know it's not because I read it that day. It's because I learned it and kept it safe in my brain because I thought it was important enough for me...." Student I looked at learning a very different way: "...it was a lot more abstract and there's a lot more you can do with it. You can manipulate it...You can manipulate things...and change them and put them in any order you want...."

Most of Edelman's findings in his theory of neuronal group selection (TNGS) were consistent with conclusions I have constructed throughout this epistemic inquiry. However, just as his philosophical bases were divergent from Maturana and Valera, so did Edelmann and I differ radically in philosophical underpinnings. Edelman self-described his views as "qualified realist" and insisted on the objective, external reality outside of the individual (p. 164).

Some people would argue this difference would negate any findings within this epistemic inquiry. I disagreed. Although complete discussion of his work, as well as a thorough discussion of different epistemological views, was not possible within the framework of the paper, I believed many points in which I concurred with TNGS needed to be emphasized.

1. Additional sprouting in which new neural process formed additional synapses could occur even in a developed brain which supported my life-long learner concept (p. 85).
2. The brain maps interacted through a reentry process resulting in emergent new functions. This reentry was the main bridge between physiology and psychology.
3. Categorization occurred on the basis of experience, not on prior programming.
4. The higher brain functions of perceptual categorization, memory, and learning were inseparable aspects of a common mental process and performance (p. 100).
5. Adaptive learning was defined as the result from the operation of neural linkages between global mappings and the value centers: "Whatever the degree of learning, behavior is constrained by ethnological factors, among the most important of which are the value systems and homeostatic requirements selected for during the evolution of the species" (pp. 100-101).
6. Recall was not stereotypic because the continual changing context changed structure and dynamics of the neural populations involved in the original categorization. The process of recategorization was continual and ongoing (p. 102).
7. Perceptual categorization and the properties of association, inexactness, and generalization were all probabilistic in nature (p. 104).
8. The further evolution of the cortex and of the organs of succession allowed much "richer sets of psychological functions with which to deal with complex environments," but no new principles other that reentry and selection were necessary (p. 107).

9. Perceptual categorization treated signals from the external world. Conceptual categorization worked within the brain involving perceptual categorization and memory regenerating in symbolic memory through language (p. 125). The theory for language was not computational nor did it insist on a language acquisition device. Thus, the inherent capacity to construct and interpret an infinite number of sentences from a finite number of words was because the "generalizing and categorizing power of a conceptual system interacting recursively with specialized language areas was unlimited" (p. 131).

10. In higher-order consciousness, there remained incompleteness of domains of mathematics, logic, and science because the pattern formation in the mind "always requires the higher-order bootstraps that are necessary for consciousness [e.g., Godel's incompleteness theorem]. Thinking occurs in terms of <u>synthesized</u> patterns, not logic and for this reason, it may always exceed in its reach syntactical, or mechanical, relationships" (pp. 151-152).

11. In each individual, sensation and perception followed unique, irreversible and idiosyncratic courses (p. 162). "Each individual is not only subject, like all material systems to the second law of thermodynamics, but also to a multilayered set of irreversible selectional events in his or her perception and memory. Indeed, selective systems are by their nature irreversible (p.168).

12. Physical laws governing actual chemical interactions making up the genetic code are deterministic. But because the "historical repertoires in which different structures can produce the same result, many degrees of freedom exist resulting in macroscopic indeterminacy" (p. 169).

13. Meaning took place dependent of categorizations based on value and was never free of affect or emotion (p. 170).
14. The mixture of events in each individual was unpredictable (p. 170). This mixture included how biochemical and early events critically shaped individual development. [I suggested here, in spite of chaos theory's insistence on initial conditions, in human beings, <u>exact</u> knowledge of these events could never be determined. Therefore the course of the individual's development was always indeterminate even using chaotic principles].
15. Because the mixture of events including society, linguistic and semantic capabilities arose with metaphor linked to thought. The capability to create new models of the world was limited only by the linkage of value and the concept of self (p. 170).
16. "Thinking [I asserted learning could be used here interchangeably] is a skill woven from experiences of the world....The acquisition of this skill requires more than experience with things; it requires social, affective and linguistic interaction" (p. 174).
17. "Thought at its highest levels is recursive and symbolic" (p. 175).
18. Ultimate explanation cannot be based on a neuroscientific explanation alone (p. 174).

THEORISTS CONVERGED

> Thus we have chosen to present things as we perceive them now, fully aware of how incomplete our answers are.
>
> ♦ Ilya Prigogine and Isabelle Stengers, 1984, <u>Order out of Chaos</u>

Autopoiesis was key to my understanding of process. Because the interactions between a living system and its environment were cognitive interactions, Maturana and

Valera (1987, 1992) defined the process of living itself as the process of cognition. Throughout their writings the basic theme was to live was to know. I have evolved in this epistemic inquiry from William James'(1890) idea of mind was a process, to Maturana and Valera's Santiago theory, to Edelman's (1992) TNGS and recursive synthesis, to Capra's (1996) web of life. Capra (1996) titled one significant chapter in his book, "A New Synthesis." This chapter was not the end of the book, but rather located in the middle. He used this chapter as a springboard for his own personal theory of life. I concluded this section of pattern, structure, and process with relevant quotes from this chapter:

> The new concept of cognition, the process of knowing, is thus much broader than that of thinking. It involves perception, emotion,and action—the entire process of life. In the human realm cognition also includes language, conceptual thinking, and all the other attributes of human consciousness (p. 175).

SIGNIFICANT POSTSCRIPT

> The rules of the game: learn everything, read everything, inquire into everything....When two texts or two assertions, or perhaps two ideas, are in contradiction, be ready to reconcile them rather than cancel one by the other; regard them as two different facets or two successive stages, of the same reality, a reality convincingly human just because it is complex.
>
> ♦ Marguerite Yourcenar, 1980, *Memoirs of Hadrian*

Brilliant Air, Brilliant Fire by Edelman (1992) was one of the last sources I read during this extended epistemic inquiry. Was that the result of an inductive study, or did I simply lock in on points of agreement. Practicing my own theory of learning meant that each successive event or experience altered the memory of past events and the interpretation of future ones. This multivocal review of literature had also allowed selective categorical construction in my personal journey of learning. Like Drake (1991), this journey was a metaphor for personal transformation, a moral dimension of who I am and who I am in the process of becoming. I now journey to the back to the classroom. Can I apply these findings of the multivocal literature to practice. Or will there be only more questions?

There is a place where the sidewalk ends
and before the street begins,
and there the grass grows soft and white
And there the sun burns crimson bright,
and there the moon-bird rests from his flight
to cool in the peppermint wind.

Let us leave this place where the smoke blows black
and the dark street winds and bends.
Past the pits where the asphalt flowers grow
We shall walk with a walk that is measured and slow,
and watch where the chalk-white arrows go
to the place where the sidewalk ends.

Yes we'll walk with a walk that is measured and slow
and we'll go where the chalk-white arrows go,
For the children, they mark, and the children, they know
the place where the sidewalk ends.

INTERLUDE 4

Students' Definitions of Learning

I pondered deeply, then, over the adventures of the jungle.

◆ Antoine de Saint-Exupéry, 1943, The Little Prince

The neuron have treelike arbors that overlap and ramify in myriad ways. Their signaling is not like that in a computer or a telephone exchange; it is more like the vast aggregate of interactive events in a jungle. And yet despite this, brains give rise to maps and circuits that automatically adapt their boundaries to changing signals.

◆ Gerald M. Edelman, 1992, Bright Air, Brilliant Fire

A sampling of student's definitions of learning was provided in this interlude for the reader's comparison and consideration. Students expressed these thoughts at the end of the indepth interviews. I asked each one of them to pause a few minutes for reflection before they responded.

1. Student I

It's not just memorizing facts. It's thinking through a situation and drawing you own conclusion. That's the key to the whole thing. Thinking through it. If you haven't thought about anything, and you haven't drawn your own conclusions and formed your own opinions or figured things out, you haven't really learned anything. All you have done is memorized a bunch of facts and that's not even close to the same thing as learning. Not even close.

2. **Student II**

I would think learning is a process of memorization and study in which you would gain knowledge from the matter [long pause]. With what you learned, if you do, you got new information you yourself know and you yourself behold. I consider that knowledge. You know the material. I guess that's pretty much it. I'm confusing myself.

3. **Student III**

It's the ability to take new stuff and fully understand and use and know the hows and whys and what it's for and apply it to real life and to remember it later on.

4. **Student IV**

Learning is the process of thinking and understanding a material or some information that you can put to use in the future [long pause]. Learning still occurs. You might not use geometry, so not everything in the future; just most of it.

5. **Student V**

I think learning is book learning, but I also think learning is experiencing new things, being able and go out and to try something you have never tried before.

6. **Student VI**

Probably the process in which the person understands and is able to recall something. And uh, I see learning as more of a practical type of matter than a....if you learn something, if something is practical I can see you learning it. If it's not really practical, I can see you just pass your way through it and get by with it. But [pause] probably more the understanding part.

7. Student VII

Learning is a process by which a person assimilates an idea or concept so that he can do it himself, so that he can understand it. Can you read that back to me?

8. Student VIII

Learning to me is just gathering information and finding out.

9. Student IX

Learning is when I comprehend new material and can recall it at a later time to use it again. It doesn't just, I don't just understand and then it leaves me. I can't remember it. Sometimes it takes me a lot of practice for me to understand it and sometimes spontaneously I understand it.

10. Student X

It's when you obtain knowledge, facts, understanding of just about anything, and when you know what to do with it.

11. Student XI

Learning would be a process that you would go through to understand, retain, and apply the information that has been give to you.

12. Student XII

I don't want to contradict myself on anything else I said. I think learning is being able to put things into action and knowing its full content [pause]. If you memorize something, it's just words coming out of your mouth. You could be thinking of anything. If you actually take a step in the right direction and so on and complete something in the right way, you can say, you learned how to do it. [to know full content] I don't know if that made any sense, but somebody else had to already learn that and explain it to you, so you have to be trustworthy of that person. [So you can't learn on your own?] Like I said, I'm not much of an innovator. People have to put things in perspective for me so I can see what I'm talking about. I'm sure you could learn on your own, if everything was stated so you could understand it or done so you could understand it.

13. Student XIII

[pause] Hum...[pause]. I guess it's not forgetting to remember something. Whatever you remember should have some use to it, some way you can use that information for your advantage.

14. Student XIV

I think it's something like someone gives you a concept - no matter whether it's academic or in life and you take it and do whatever you want with it. You can expand on it, or take it like they taught you, and be able to contribute back to your environment.

15. Student XV

Well, I think it was just what I was talking about, I think learning is when you are introduced to something new, something you don't know about and you get an understanding of it and then you use it. Then you use it. You capitalize on what you've just been told or just been introduced to and it stays with you. It's like Algebra. You always hear about people who say, "Uh, when are we going to use Algebra in later life?" but you use it all the time. Geometry, a lot of the things. I think it just stays with you—all the time.

CHAPTER 4

THE MODERN HERO: PRIGOGINE IN THE CLASSROOM

Thinking about Thinking

> The shift of language from physics to bioiogy is an important one....Images of forces, trajectories and direct causes are replaced with thinking about thinking...constant change and complete interdependencies.
>
> ♦ Brent Davis and Dennis Sumara, 1997, Harvard Educational Review

In the classic book that introduced chaos science to the world, Gleick (1987) dedicated an entire chapter to a group known as the Dynamical Systems Collective—Robert Shaw, Doyne Farmer, Norman Packard, and James Crutchfield. These four men were credited with developing the theories of chaos. In 1977, there was no one to teach a course or supervise the field of chaos. No one had received a doctorate in the field, but these four men literally risked their futures by choosing their field of study of dynamic chaos: "They enchanted themselves and dismayed their professors with leaps to questions of determinism, the nature of intelligence, the direction of biological evolution" (Gleick, pp. 250-251).

But Waldrop (1992) recounted by the time the book appeared on the bookshelf, the Dynamic Systems Collective had already gotten bored with this new and innovative field:

> ...Farmer and Packard were both getting downright bored with chaos theory. As Farmer says, "So what? The basic theory of chaos was already

> fleshed out." He wanted the excitement of being on the frontier, where things were not well understood. Packard for his part, wanted to get his hands dirty with some real complexity (p. 131).

By the time the researcher read the new theories and ideas, the theoretical creators had often moved on. Just about the time I thought chaos provided answers to my questions about learning, science had moved on. I, too, realized what chaos had brought to the world—the image of the elegant fractals creating patterns replicated in diminishing beauty like a W. C. Escher etching of unending circularity. Chaos brought dynamic non-linearity into the world of the non-scientists and proved in simple mathematical terms complex unpredictability. Chaos introduced self-organization in Prigogine's dissipating structures. Chaos redefined the arrow of time and irreversibility. Chaos demanded paradox and metaphor in the macroworld as quantum physics required imagery and intuition in the microworld—order and chaos, determinism and unpredictability; simplicity and complexity.

But chaos simply could not go far enough to explain the complex structures of the human brain. Again, Farmer, one of chaos' originators described this limitation:

> Besides…chaos theory by itself didn't go far enough. I told you a lot about how certain simple rules of behavior could give rise to astonishingly complicated dynamics. But despite all the beautiful pictures of fractals and such, chaos theory actually had very little to say about the fundamental principles of living systems or of evolution. It didn't explain how systems starting out in the state of random nothingness could then organize themselves into complex wholes (Waldrop,1992, p. 287).

To discover questions about learning, I used qualitative inductive methods of grounded theory, multivocal literature and indepth interviews. I moved into complexity theory, an extension of the story of order "a kind of deep, inner creativity that is woven into the very fabric of nature" (Waldrop, 1992, p. 102). As I journeyed into realms so complex, language had again been challenged to create new metaphors even to glimpse at the possibilities. Complex adaptive systems were "intertwining process[es] of emergence and adaptation…as emergent structures growing from some deeper neural substrata that is constantly being adjusted and readjusted….Like clouds emerging from the physics and chemistry from water vapor, concepts are fuzzy, shifting dynamic things…" (Waldrop, pp. 149, 183).

From complexity and shifting dynamic things, what had I learned about learning? Learning could not be limited by Newton and his clocklike world. Learning could not be explained by the behavioristic definition of a reaction to external stimuli through linear cause and effect. Learning was a personal response with structural changes in a nonlinear organizationally closed autopoietic network. It incorporated lifelong learning particular to the individual, but also universal and monomythic to humankind. Learning involved the sacred quest within each person.

In the Indo-European tradition, learning meant to track or to furrow. However, my meaning had evolved from the etymology of the past and from the cultural context of the classroom – to get knowledge by study, experience, or instruction. The act of constructing a reality of the world became my focus; and learning, the act of knowing, and cognition synthesized towards awareness, action, and values.

Suddenly within all the metaphors, I realized I was describing myself. I realized no matter how I integrated all the disparate ideas of the research, I ultimately only glimpsed at the answers or discovered only partial explanations to my personal questioning: What is learning? What is the mind? What does our journey mean? I had gone full circle from the beginning of this epistemic inquiry to universal questions—What is the stuff of the world? What is the universe made of? What is life?

The Nature of Complexity

> Learning occurs on a number of levels and in a variety of manners—this is the nature of complexity.
>
> ♦ William Doll, Jr., 1989, Educational Leadership

The grounded theory emerged as an epistemic inquiry. The framework of chaos evolved to constructs of complexity. The review of the learning theorists incorporated such diverse voices as Dewey, Skinner, Eisner, and von Glasersfeld. The many voices of psychology ranged from James, Jung, Hebb, and Bateson. The participant observation transformed the multivocal literature to the dialogue with students. My theory emerged as practice for the classroom as I experienced a transformational change in my own personal pedagogy.

Of the writers I read in the diverse fields, I credited three men with the bases of my understanding of how I and others learn. Ilya Prigogine, the Nobel prize winner, described dissipative structures so I could visualize the evolving from disorder to higher complexities of order and creative thought. Maturana and Valera provided understanding into the process of life itself through autopoiesis which literally meant self-poetry. These biologists integrated the importance of self-organization. Fritjof Capra provided the three terms of pattern, structure, and process to frame my final thoughts.

These writers also emphasized the open social interconnections and philosophical connotations of language and languaging. Through language and communication, individuals constructed a world, "the world everyone sees is not the world but a world, which we bring forth to others" (Maturana & Varela, 1987, p. 245). With languaging, individuals also experienced reflective consciousness, "As we know how we know, we bring forth ourselves" (Maturana & Varela, 1987, p. 244). Mind and learning became processes identified with life itself.

In summary, through exploratory methods, I found power in connection and pattern, creativity in chaos and structure, and evolution in complexity and organization. I used inductive methods of grounded theory, indepth interviews, and multivocal literature to see if in my journey, I could discover what questions to ask. I now could use learning, the act of knowing, and cognition interchangeably; I could define this synthesis of learning through pattern, process and structure. Beyond the metaphor of the journey of the life-long learner was philosophical response to a ultimate question: learning was life.

Transformation of Definition

> In Taoism there is no inherent order. "The world started as one, and the one becomes two, and the two became many, and the many led to myriad things." The universe in Taoism is perceived as vast, amorphous, and ever-changing. You can never nail it down. The elements always stay the same, yet they're always rearranging themselves. So it's like a kaleidoscope: the world is a matter of patterns than change, that partly repeat, but never quite repeat, that are always new and different.
>
> ♦ M. Mitchell Waldrop, 1992, Complexity

When I looked at the terms of pattern, structure and process, this triad became not three distinct parts of one definition, but rather an overlapping, circular integration of all three in one. I returned to Student I and the first interview. With her unusual perspicacity, she clarified the first term, pattern:

> And sometimes you have to go back and retrace your steps, but it's like the pieces of a puzzle and you have to fit them together in just the right way. And there's a certain pattern to it, but it's a little different with every problem.

Patterns connected myth and metaphor. Pattern was also intricately related to the dynamics and nonlinear processes of self-organization. Within each new pattern of learning, the individual constructed creative thought. Once the processes of mind changed the structures of the mind brain, new patterns emerged in evolutionary terms of higher complexity. Waldrop (1992) appropriately used the term "perpetual novelty" (p. 295). However, the word pattern extended beyond the neural mappings of creative thought. Gregory Bateson summarized the extension: "The pattern which connects the orchid to the primrose and the dolphin to the whale and all four of them to me" (Capra and Steindl-Rast, 1991, p. 14).

The second term was structure. The complexity of the structure of the brain was incomprehensible from a single neuron to the estimated one million billion connections in the cortical sheet. Edelman (1992) provided an excellent example of that astronomical number. If I counted those connections one per second, it would take me thirty-two million years to finish counting (p. 17). However, structure also went beyond the physiological explanation. It incorporated Maturana and Varela's essence of overall organization. Kiel and Elliot (1997) explained the abstraction of structure:

> Structure is not something we see....since structure is an abstraction, it cannot be defined by enumerating material characteristics of the system. It must instead be defined by the arrangement of the system's parts and by the principle of that arrangement. Structure is a system-wide component that makes it possible to think of the system as a whole. It is this structure that makes a chaotic system indecomposable. The whole is complex (disorder), but it is united by a common endogenous structure (order), whereby the system cannot be broken down....(K. Waltz (1979), Theory of International Politics, New York: McGraw-Hill, pp. 79-80 as cited in Kiel and Elliot, (1997), p. 111).

Student I explained this concept of structure as well as any researcher:

> There are certain things you need to know. It's like tools, like a carpenter would have. You've got you nail and your hammer and your wood, and you can make anything you want to. You have your tools, your basic knowledge....You can develop it in any direction you want just by sitting down and thinking or trying to work through a problem or developing an opinion. It's the same basic concept for any subject you choose.

She also explained the complexity of the third component, process, eloquently:

> Developing is a lot more important than the knowing...Reading is a thinking process. Same thing. Learning is too....That's the key to the

> whole thing. Thinking through it. If you haven't thought about anything, and you haven't drawn your own conclusions and formed your own opinions or figured things you, you haven't really learned anything. All you have done is memorized a bunch of facts and that's not even close to the same thing as learning. Not even close.

The third term, process, inferred the inclusiveness of multiple constructs. Process reflected the three terms of learning—learning, the act of knowing, and cognition. Process incorporated the structural, chemical, and electrical changes within the neuronal network. Process illustrated the ideas of dissipative structures and autopoiesis. Process was the summative term where mind and cognition defined life itself.

The Cultural Context

> My models were the people who stepped outside the conventional mind and who could actually stop my mind and completely open it up and free it, even for a moment, from a conventional, habitual way of looking at things....If you are really preparing for groundlessness, preparing for the reality of human existence, you are living on the razor's edge, and you must become used to the fact that things shift and change. Things are not certain and they do not last and you do not know what is going to happen. My teachers have always pushed me over the cliff....
>
> ♦ PemaChodron, Tricycle (as cited in bell hooks, 1994, Teaching to Transgress)

Jerome Bruner (1996) in The Culture of Education abruptly reminded me to go beyond the research and theory of mind back to the classroom: "Without specification of resources and settings required, a theory of mind is all 'inside-out' and of limited applicability to education. It comes interesting only when it becomes "outside in," indicating the kind of world needed to make it possible to use mind (or heart) effectively" (p. 9).

Following Bruner's suggestion, I returned to the classroom of trigonometry for that last day of participant observation and my experience of nonlearning mathematics:

> The class moved along day by day—sometimes intense, sometimes casual. The difference in attitude during test taking was reflective of the difficulty of the material. The last day, I had to assume the role of a teacher as I dealt with an upset mother. I came in late. My notes were filled with trig. The students overall appeared sleepy, but they seemed to solve the problems without much effort. I still didn't have a clue to the meaning of the formulas and the foreignness of the trig language.

Bruner discussed extensively the role of culture and the institution of public schools. "Culture shapes the mind...provides us with the toolkit by which we construct not only our worlds but our very concepts of self." I immediately noticed he used the same imagery as Student I.

Miller (1993) discussed the idea of the dialectical process of integrating ideas of learning within the cultural-sociological. Miller described this process in Vygotskian terms: "The dialectical process operates mainly during interaction with adults, more skilled peers, or peers of equal ability...Movement through the zone is a dialectical process as the [student] collaborates with another person and they co-construct the meaning of the task, a goal and a solution" (pp. 421-422).

Through biographical sketches of famous creative persons in a wide variety of disciplines, Howard Gardner (1993) discussed requirements to develop the creative person. He strongly maintained "that the creator required both the affective support from someone with whom he or she felt comfortable and the cognitive support from someone who could understand the nature of the breakthrough" (pp. 43-44).

Again the students affirmed these writers' conclusions. Many of the students expressed needing help understanding some difficulty in the math class. However, they usually did not turn to the teacher for help but rather to another peer. For example, Student I was the only freshman in class, taking classes almost two years ahead of her peers. However, her school experience had not been positive. She discussed why she pushed to excel; it was in spite of a fifth grade teacher and constant teasing from classmates.

In contrast, Student II described her feelings towards the trigonometry class and students in terms of family: "Well, the students, we all kind of like a family now—we all know each other. We've been there for almost two and one-half years now and we get along and we work well together." Student V concurred, "Uh, I feel good when I go in there, not oh great, but uh, I just feel good when I go in there. I know the people and everything."

Student VI also agreed about how everyone got along even teaching themselves when Mr. Sine was not there:

> I feel it gets along real well. I like the group of people in there. There's no one who thinks they are any better than anyone else. If you have a problem, anyone in the class will come over and help you. Uh, it's all real positive. It's just a good working relationship. Even when [Mr. Sine] was gone, we still managed to go through a chapter teaching by ourselves.

Through a positive relationship, the students accepted working with each other and progressed in the learning process because of these relationships. In most instances the students referred to "we or us" rather than "I." Their responses affirmed trust and security within the culture and context of schooling facilitating and enhancing the learning process.

CREATING THE PARADISE

> And, after a long, lonesome and scary time...
> ...the people listened,
> and began to hear...
> And to see God in one another...
> ...and in the beauty of all the Earth.
> And Old Turtle **smiled**.
>
> And so did God.

◆ Douglas Wood, 1992, Old Turtle

In the preface I credited Dr. Lepushitz for saying the right things to me at the right time. We met in the classroom of child development, and she introduced me to a wide array of unfamiliar literature. At the peak of my discouragement and disillusionment about the doctoral program, I completed a review of a book which later had major significance to my spiritual life—a component of my life I almost had forgotten in the midst of graduate school. Part of her response to my writing was "...Thank you for sharing your journey with me.

I had never considered the role of student as a "sharing of the journey.

belle hooks [sic] (1994) wrote of the sharing of the journey from the student perspective:

> I felt a deep kinship, for I have sought teachers in all areas of my life who would challenge me beyond what I might select for myself, and in and through that challenge allow me a space of radical openness where I am truly free to choose—able to learn and grow without limits. The academy is not a paradise. But learning is a place where paradise can be created. The classroom, with all its limitations, remains a location of possibility (p. 207).

Within all the possibilities offered in this epistemic inquiry, the final question became how do educators create this paradise of learning and possibility? If learning was equated with the computer and knowledge with data, the persons involved became inert pieces of test results. Only in schools were questions posed when the answers were already known.

Davis and Sumara (1997) wrote a powerful article concerning today's current practices in the classrooms and in the college preparatory teaching programs. Their thesis was educators were confronted with noncompatible theories and issues. Implementing reforms and mandates incorporated incommensurates—back to basics, student-centered instruction, formalized and standardized evaluations. The metaphors of everyday language transformed practice and became entrenched in the institution of schooling: "The metaphors we use eventually become literalized and woven seamless into our everyday beliefs and practices—so completely that their figurative aspects dissolve into transparency" (p. 108). These authors suggested a blurring of teaching and learning to be defined as "mutually specifying, co-emergent, pervasive, and evolving practices that are at the core of our culture's efforts at self-organization and self-renewal" (p. 124).

Their suggestions was philosophically consistent with the intent of this epistemic inquiry. To focus back to the classroom, the research of the multivoices could be integrated, but the students voices could not be discounted. The dialogues of the fifteen students iterated the stuff of isolated facts and memorization, the boredom of repetition, and activities not related to any world outside the classroom. They were not asking for problems to be easier; they sought challenge. They rejoiced when they finally solved a difficult problem. The students in this epistemic study simply told me they wanted experiences to recreate their world with a partnership of the teacher, their peers, and themselves.

They were asking for the freedom to look at multiple ways of learning and solving complex ideas. If this group of high school students were in any way characteristic to the students across the country, educators must be willing to hear their voice. Educators must be active participants always seeking new understandings and willing to engage in new dialogues. Educators must continue the personal journeys of learning and discover and rediscover what the multivoices of diverse disciplines can offer for the daily practices in the classroom.

Each person must be an active participant always seeking new understandings and his or her own creative self-organization. Each must be willing to engage in transformational dialogue. To define learning and life itself, each must follow the interrelated epistemic inquiry of the world. Lao-tse understood: "The wise [person] looks into space, and does not regard the small as too little, nor the great as too big; for he [or she] knows that there is no limit to dimensions."

INTERLUDE 5

The Child as the Epistemologist

> A great deal is offered to students in school that is not a function of choice but rather a function of tradition. Much of what we teach, we teach because it has always been taught.
>
> -- Elliot Eisner, 1985, The Educational Imagination

Within many current educational practices, the child as the epistemologist was forgotten. Information rather than ideas, memorization rather than integrated patterns, simplification rather than presentation of the complex represented the norms of the classrooms. At the end of one interview, Student IV paused and then gave me a scathing critique on practices of teachers:

> I have always wanted to tell someone, a teacher, about my opinion of taking notes they write down for us, and then put it on the overhead, and we look at it, and copy it down. I mean I don't really think that is a good thing. I think it is better for the teacher just to say it like lecture and make us self-learn from our notes, self-learn from our own notes instead of just copying form the overhead. Because [students] are copying it down and not learning anything. Some teachers just give the overhead and lecture at the same time. Well, [they're] not going to hear it; they're just going to

> write down the notes. I don't learn that way. I think it is better if the teacher lectures and lets me take notes what I think is important.

In many of the interviews, the students also distinguished between learning and memorization. Student I emphatically stated memorization of facts was not even close to learning. Other students also disliked the memory requirement. Student II applied the same critique to English: "You still gotta memorize and know what you're doing. In English you have to memorize where verbs go and in any other subject you have to memorize so where you can test and remember the material and Trig is memorization of formulas, degrees and all kinds of stuff."

Explaining and preferring a challenge, Student III critiqued the routine of school in behavioristic terms: "Some classes are real interesting like computer class; and some classes are useful like typing; but then there are some very boring classes like English where you just learn the same stuff over and over; and there's nothing new; and I think that's just a waste of time."

A challenge or stuff – that seemed to be the choice. Feelings were also closely related to the concepts of learning. Student VII discussed these feelings and <u>lack of</u> when associated with memory:

> Uh, if you learn something, personal pride. Feel good about yourself because you know that you have learned something. When you are in a class and you're trying to learn everything and you are and actually going below the surface, you feel good about it. You feel good when you take a good test because you know you understood it. When you take a test, like

a memorization test, there's no good feeling in that. You just memorized stuff.

So, how does the educator determine the challenge and discard the stuff? I strongly feel educators need seriously to reconsider their own practices and beliefs. I do not want to conclude this study with an oversimplification or how-to-do cookbook recipe for the classroom. I realize listing suggestions still assumes a quick-fix approach; however, I emphasize pedagogy cannot be transformed by implementing a few suggestions or extracting catchy sayings.

However, as I reviewed the multivocal literature, what I discarded in my personal toolkit of educational thought was part of my journey of learning.

Discards:

1. Learning is defined within the arrow of time, one-directional. Stage theorists do not explain fully learning within a hierarchial context.
2. Learning as process is similar at all age levels. Lived experiences allow increased patterning and complex interconnections to occur. Age appropriate or developmentally ready arguments often limit rather than enhance learning. Limitations for the very young or the very old are not viable within this context.
3. Right/left brain theories and male/female differences are not consistent with current biological and neurophysical findings. Explanations for those theories and other similar theories are more contextually and culturally bound rather than inherent in structure and organization.
4. Extensive use of lecture and dittos limit students as epistemologists. "Dittos don't make dendrites" and "one-size-fits-all textbooks" are appropriate warnings in this

context if learners are considered pattern seekers (Kovalik and Olsen, 1993, p. 13-14).

5. Parnell (1996) described the freezer approach to teaching and learning. "In handing out information to our students…[we in effect say] 'Just put this in your mental freezer; you can thaw it out later should you need it.'" Rote memorization without contextual application would also be included in this caution.
6. Controlled learning through segmented discussions and simplified examples limits diverse thinking.
7. Nature versus nurture arguments provide placement of blame rather than construction of learning. All students can learn.

How would I transform the classroom? What would I add to my toolkit? Classrooms offer limitless opportunities. Actually, my ideas are not really new. Vygotsky, constructivists, constructionists and even the current educational bandwagon of brain-based learning offer possibilities for transformation.

Opportunities:

8. Caine and Caine (1995) suggested "orchestrated complexity" (p. 46). Immersion in the complex world rather than simplified context is essential.
9. An emphasis on primary sources and interactive materials allows the students and the teachers to learn together.
10. Students in the interviews repeatedly asked for challenges, not easy solutions.

11. Relaxed alertness was a positive descriptor within the classroom of trigonometry. Students and the teacher were comfortable in the setting, but actively engaged in the learning process.
12. The teacher should be a facilitating agent encouraging dialogue rather than be a traditional authoritative lecturer.
13. Cognitive terminology should be used in questioning techniques asking students to explain Why? How? What are you thinking?
14. Questions should be open-ended rather than preformulated by the teacher with set answers.

Maxine Greene used the term "inward search to possibilize" in a lecture last year (Fall, 1997 at Oklahoma State University). I believe this succinct phrase is the appropriate summary.

SELECTED BIBLIOGRAPHY

Alexander, P., Schallert, D., & Hare, V. (1991). Coming to terms: How researchers in learning and literacy talk about knowledge. Review of Educational Research, 61, 265-286.

Alton-Lee, A., & Nuthall, G. (1990). Pupil experiences and pupil learning in the elementary classroom: An illustration of a generative methodology. Teaching and Teacher Education, 6, 27-45.

Armstrong, T. (1994). Multiple intelligences in the classroom. Alexandria, VA: The Association for Supervision and Curriculum Development.

Astington, J. (1993). The child's discovery of the mind. Cambridge, MA: Harvard University Press.

Barrow, J. (1991). Theories of everything: The question for ultimate explanation. New York: Fawcett Columbine.

Bauersfield, H. (1995). The structuring of structures: Development and function of mathematizing as a social process. In L. Steffe & J. Gale (Eds.), Constructivism in Education (pp. 137-158). Hillsdale, NJ: Lawrence Erlbaum Associates.

Beilin, H. (1989). Piagetian theory. In R.Vasta (Ed.), Annals of child development, Vol. 6 (pp. 85-132). Greenwich, CT: JAI Press.

Bereiter, C. (1990). Aspects of an educational learning theory. Review of Educational Review, 60, 603-624.

Bertalanffy, L. (1933). Modern theories of development: An introduction to theoretical biology. London: Oxford University Press.

Bertalanffy, L. (1952). Problems of life: An evaluation of modern biological thought. New York: John Wiley & Sons.

Bertalanffy, L. (1968). General Systems Theory. New York: Braziller.

Bertalanffy, L. (1975). Perspectives on general system theory: Scientific-philosophical studies. New York: George Braziller.

Blackerby, R. (1993). Application of chaos theory to psychological models. [On-line 1/6/98]. Available: http://www.perfstrat.com/rfb/sciproc.htm

Blair, B. (1993). What does chaos theory have to offer educational administration? Journal of School Leadership, 3 (5), 579-96.

Bloom, A. (1987). The closing of the American mind. New York: Simon & Schuster.

Boyatzis, R., & Kolb, D. (1991). Assessing individuality in learning: The learning skills profile. Educational Psychology, 11, 279-295.

Bradley, S. (Producer & Director). (1990). The quantum universe [Videotape]. WETA and the Smithsonian Institution: Wentworth Films.

Briggs, J., & Peat, F. (1989). Turbulent Mirror. New York: Harper & Row.

Bringueir, J. (1980). Conversations with Jean Piaget. Chicago: University of Chicago Press.

Brofenbrenner, U. (1989). Ecological systems theory. In R.Vasta (Ed.), Annals of child development, Vol. 6 (pp. 187-250). Greenwich, CT: JAI Press.

Brooks, J., & Brooks, M. (1993). In search of understanding: The case for constructivist classrooms. Alexandria, VA: The Association for Supervision and Curriculum Development.

Brown, D. (1989). Towards a paradigm of promise. Unpublished doctoral dissertation, Oklahoma State University, Stillwater.

Brown, T. (1994). Creating and knowing mathematics through language and experience. Educational Studies in Mathematics, 27 (1), 79-80.

Bruer, J. (1997). A science of learning. The American School Board Journal, 184 (2), 24-27.

Bruner, J. (1983). In search of mind: Essays in autobiography. New York: Harper & Row.

Bruner, J. (1996). The culture of education. Cambridge, MA: Harvard University Press.

Butz, M. (1995). Chaos theory, philosophically old, scientifically new. Counseling and Values, 39 (2), 84-98.

Caine, R., & Caine, G. (1995). Reinventing schools through brain-based learning. Educational Leadership, 52 (7), 43-47.

Campbell, J. (1974). The hero with a thousand faces. New York: Meridian Books.

Campbell, J. (1986). The inner reaches of outer space: Metaphor as myth and as religion. New York: Harper & Row.

Campbell, J. (1990). Transformations of myth through time. New York: Harper & Row.

Campbell, J., & Moyers, B. (1988). The power of myth. New York: Doubleday.

Capra, F. (1982). The turning point: Science, society, and the rising culture. Toronto: Bantam Books.

Capra, F. (1983). The tao of physics (2nd ed). Boston: The New Science Library.

Capra, F. (1996). The web of life. New York: Anchor Books.

Capra, F., & Steindl-Rast, D. (1991). Belonging to the universe: Explorations on the frontiers of science and spirituality. San Francisco: Harper Collins.

Carnine, D. (1990, January). New research on the brain: Implications for instruction. Phi Delta Kappan, 71 (5), 372-377.

Casti, J. (1989). Paradigms lost: Tackling the unanswered mysteries of modern science. New York: Avon Books.

Casti, J. (1990). Searching for certainty: What scientists can know about the future. New York: William Morrow and Company.

Casti, J. (1994). COMPLEXification: Explaining a paradoxical world through the science of surprise. New York: Harpercollins.

Cobb, E. (1977). The ecology of imagination in childhood. New York: Columbia University Press.

Cohen, J., & Stewart, I. (1994). The collapse of chaos: Discovering simplicity in a complex world. New York: Viking.

Cole, M., John-Steiner, V., Scribner, S., & Souberman, E. (Eds.). L.S. Vygotsky Mind in society: The development of higher psychological processes. Cambridge, MA: Harvard University Press.

Combs, A. (1982). A personal approach to teaching: Beliefs that make a difference. Boston: Allyn & Bacon.

Conrad, C. (1982). Grounded theory: An alternative approach to research in higher education. The Review of Higher Education, 5 (4), 239-249.

Cooper, L. (1988). Local and global factors in learning. In J. Davis, R. Newburgh, & E. Wegman, E. (Eds.). Brain structure, learning, and memory (pp. 171-191). Aaas Selected Symposium, No. 105. Boulder, CO: Westview Press

Coxford, A. (1987). Trigonometry (Rev. ed.). Orlando, FL: Harcourt Brace Jovanovich.

Crichton, M. (1990). Jurassic Park. New York: Alfred A. Knopf.

Cziko, G. (1992). Purposeful behavior as the control of perception: Implications for educational research. Educational Researcher, 21 (9), 10-18.

Davis, B. & Sumara, D. (1997). Cognition, complexity, and teacher education. Harvard Educational Review, 67 (1), 105-125.

de Saint-Exupéry, Antoine. (1943). The little prince (K. Woods, Trans.) San Diego, CA: Harcourt Brace Jovanovich.

DeVries, R. (1997). Piaget's social theory. Educational Researcher, 26 (2), 4-17.

Dewey, J. (1916). Democracy and education. New York: Macmillan.

Dobson, R., & Dobson, J. (1990). Curriculum theorizing: Towards an emerging paradigm. Unpublished manuscript.

Dobson, R., Dobson, J., & Koetting, J. (1985). Looking at, talking about and living with children: Reflections on the process of schooling. Lanham, MD: University Press of America.

Dobson, R., Dobson, J., & Smiley, F. (1991). Quantum reality: An emerging metaphor for curriculum workers. OASCD Journal, 3, 40-45.

Doll, W. (1989). Complexity in the classroom. Educational Leadership, 7 (1), 65-70.

Drake, S. (1991). The journey of the learner: Personal and universal story. The Educational Forum, 56, 47-59.

Edelman, G. (1992). Bright air, brilliant fire: On the matter of the mind. New York: BasicBooks.

Eisner, E. (1985). The educational imagination: On the design and evaluation of school programs (2nd ed.). New York: Macmillan.

Emerson, R. (Ed.). (1988). Contemporary field research: A collection of readings. Prospect Heights, IL: Waveland Press.

Ennis, C. (1992). Reconceptualizing learning as a dynamical system. Journal of Curriculum and Supervision, 7 (2), 115-120.

Favre, A., Guitton, H., Guitton, J., Lichnerowicz, A., & Wolff, E. (1995). Chaos and determinism: turbulence as a paradigm for complex systems converging toward final states (B. Schwarzbach, Trans.). Baltimore: The John Hopkins University Press.

Ferguson, M. (1978). Karl Pribram's changing reality. In K. Wilbur (Ed.), The Holographic Paradigm and Other Paradoxes: Exploring the Leading Edge of Science (pp. 15-26). Boston: New Science Library.

Ferguson, M. (1987). The aquarian conspiracy: Personal and social transformation in our time. Los Angeles: J.P.Tarcher.

A few clues about autopoiesis terminology. [On-line 6/23/98]. Available: http://bart.northnet.com.au/~pfell/glossary.html

Fogel, A. & Thelan, E. (1987). Development of early expressive and communicative action: Reinterpreting the evidence from a dynamic systems perspective. Developmental Psychology, 23, 747-761.

Forester, L. (1992). Intuitive thought in process knowledge: Implications for curriculum theorizing. Unpublished doctoral dissertation, Oklahoma State University, Stillwater.

Friere, P. (1970). Pedagogy of the oppressed (M. Ramos, Trans.). New York: Herder and Herder.

Gardner, H. (1993). Creating minds: An anatomy of creativity. New York: BasicBooks.

Gardner, H. (1993). Multiple intelligences: The theory in practice. New York: BasicBooks.

Garmston, R. & Wellman, B. (1995). Adaptive schools in a quantum universe. Educational Leadership, 52 (7), 6-12.

Garrison, M. (1988). Relativity, complementarity, indeterminacy, and psychological theory. The Journal of Mind and Behavior, 9 (2), 113-135.

Glaser, B. (1978). Theoretical sensitivity. Mill Valley, CA: The Sociological Press.

Glaser, B., & Strauss, A. (1967). Discovery of grounded theory: Strategies for qualitative research. New York: Walter de Gruyter.

Gleick, J. (1987). Chaos: Making a new science. New York: Viking.

Gribbin, J. (1984). In search of Schrodinger's cat: Quantum physics and reality. New York: Bantam Books.

Griffith, D., Hart, A., & Blair, B. (1991). Still another approach to administration: Chaos theory. Educational Administration Quarterly, 27 (3), 430-51.

Goswami, A. (1988). Creativity and the quantum theory. The Journal of Creative Behavior, 22 (1), 9-30.

Guess, D., & Sailor, W. (1993). Chaos theory and the study of human behavior: Implications for special education and developmental disabilities. The Journal of Special Education, 27 (1), 16-34.

Haken, H. (1983). Synergetics: An introduction. Berlin: Springer-Verglag.

Hall, N. (Ed.). (1991). Exploring chaos: A guide to the new science of disorder. New York: W. W. Norton.

Hampden-Turner, C. (1981). Maps of the mind. New York: Macmillan.

Hayles, N. (1990). Chaos bound: Orderly disorder in contemporary literature and science. Ithaca, NY: Cornell University Press.

Healy, J. (1987). Your child's growing mind: A guide to learning and brain development from birth to adolescence. New York: Doubleday.

Healy, J. (1990). Endangered minds: Why children don't think and what we can do about it. New York: Simon & Schuster.

Herbert, N. (1993) Elemental mind: Human consciousness and the new physics. New York: Plume.

Hergenhahn, B. (1988). An introduction to theories of learning (3rd ed.). Englewood Cliffs, NJ: Prentice Hall.

Hofstadter, D. (1979). Gödel, Escher, Bach: An eternal golden braid. New York: Vintage Books.

Holayter, M., & Sheldon, D. (1994). Order out of chaos. The Executive Educator, 16 (10), 20-23.

Holland, J. (1998). Emergence from chaos to order. Reading, MA: Helix Books.

hooks, b. (1994). Teaching to transgress: Education as the practice of freedom. New York: Routledge.

Holt, J. (1995). How children learn (Classics in child development) (Rev. ed.). Reding, MA: Addison Wesley.

Houghton, R. (1989). A chaotic paradigm: An alternative world view of the foundations for educational inquiry. Unpublished doctoral dissertation, University of Wisconsin, Madison.

Huebner, D. (1975). Curricular language and classroom meanings. In W. Pinar (Ed.), Curriculum theorizing: The reconceptualists (pp. 217-236). Berkeley, CA: McCuthan Publishing.

Iran-Nejad, A. (1990). Active and dynamic self-regulation of learning processes. Review of Educational Research, 60, 573-602.

James, W. (1890). The principles of psychology (reprint, 1983). Cambridge, MA: Harvard University Press.

Janesick, V. (1982). Construction grounded theory: Reflections on a case study of architectural design. Studies in Art Education, 24, 16-24.

Jones, R. (1994). Chaos theory. Executive Educator, 16 (10), 20-23.

Jones, R. (1995). Smart brains. American School Board Journal, 182 (11), 22-26.

Kant, I. (1783). Conclusion: On the determination of the bounds of pure reason. The Internet Encyclopedia of Philosophy. [On-line 2/15/98]. Available: http://www.utm.edu/research/iep/text/kant/prolegom/pro-conc.htm

Katz, L., & Chard, S. (1989). Engaging children's minds: The project approach. Norwood, NJ: Ablex Publishing.

Kelly, G. (1997). Research traditions in comparative context: A philosophical challenge to radical constructivism. Science Education, 81 (3), 355-375.

Kelso, J., Scholz, J., & Schoner, G. (1986). Nonequilibrium phase transitions in coordinated biological motion: Critical fluctuations. Physics Letters A, 118, 279-284.

Kiel, L., & Elliott, E. (Eds.). (1997). Chaos: Theory in the social sciences. Ann Arbor, MI: The University of Michigan Press.

Kieren, T. (1990, April). A note on determinism and predictability in education research and practice. Paper presented at the annual meeting of the American Educational Research Association, Boston, MA.

Kieren, T. (1990). Understanding for teaching for understanding. The Alberta Journal of Educational Research, 36, 191-201.

Kotulak, R. (1996). Inside the brain: Revolutionary discoveries of how the mind works. Kansas City, MO: Andrews and McMeel.

Kovalik, S., & Olsen, K. (1993, October). What is the "best available knowledge" about how the human brain learns? Quality Outcomes-Driven Education, 13-16.

Krishnamurti, J. (1978). The wholeness of life. India: Krishnamurti Foundation.

Kresh, Y. (1998). The brain and heart of chaos. [On-line 1/6/98]. Available: http://husol.auhs.edu/chaosjk1.htm

Kuhn, T. (1970). The structure of scientific revolutions (2nd ed.). Chicago: The University of Chicago Press.

The latest on how the brain works. (1997, April). NEA Today, 17.

Lawler, R. (1990). A theory of human cognition constructing knowledge from interactions. The Journal of Mathematical Behavior, 9, 177-192.

Lehrer, R., Serlin, R., & Amundson, R. (1990). Knowledge or certainty? A reply to Cziko. Educational Researcher, 19 (6), 16-19.

Lerman, S. (1996). Intersubjectivity in mathematics learning: A challenge to the radical constructivist paradigm. Journal for Research in Mathematics Education, 27 (2), 133-150.

Leshan, L., & Margenau, H. (1982). Einstein's space and Van Gogh's sky: Physical reality and beyond. New York: Collier Books.

Lindbergh, A. (1955, 1975). Gift from the sea. New York: Pantheon Books.

Magee, N. (1998). Determinism, total predictability and the uncertainty principle in chaotic systems: Theological implications. [On-line 2/16/98]. Available: http://mars.superlink,net/~nmagee/chaos.html

Marzano, R. (1992). A different kind of classroom: Teaching with dimensions of learning. Alexandria, VA: Association for Supervision and Curriculum Development.

Maturana, H. (1998). Metadesign, Part 1. [On-line 1/24/98]. Available: http://www.inteco.cl/articulos/metadesign_parte1.htm

Maturana, H., Mpodozis, J., & Letelier, J. (1995). Brain, language and the origin of human mental functions. Biological Research, 28, 15-26. [On-line 1/25/98]. Available: http://www.informatik.umu.se/~rwhit/MatMpo&Let(1995).html

Maturana, H., & Varela, F. (1987). The tree of knowledge: The biological roots of human understanding. Boston: Shambhala/New Science Press.

Millay, E. (1956). Collected poems. New York: Harper & Row.

Miller, P. (1993). Theories of developmental psychology. New York: W. H. Freeman.

Minnis, J. (1985). Ethnography, case study, grounded theory and distance education research. Distance Education, 6, 189-198.

Moran, A. (1991). What can learning styles research learn from cognitive psychology? Educational Psychology, 11, 239-245.

Moyers, B. (1989). A world of ideas. New York: Doubleday.

Nadis, S. (1993). Kid's brainpower: Use it or lose it. Technology Review, 96, 19-20.

Nummela, R., & Rosengren, T. (1988, April). The brain's routes and maps: Vital connections in learning. NASSP Bulletin, 83-86.

Ogawa, R., & Malen, B. (1991). Towards rigor in reviews of multivocal literature: Applying the exploratory case study method. Review of Educational Research, 61, 265-286.

Ornstein, R. (1991). Evolution of consciousness: The origins of the way we think. New York: Simon & Schuster.

Oyama, S. (1985). The ontogeny of information: Developmental systems and evolution. Cambridge, MA: Cambridge University Press.

Parnell, D. (1996, March). Cerebral context. Vocational Education Journal, (pp. 18-21, 50).

Peat, F. (1987). Synchronicity: The bridge between matter and mind. Toronto: Bantam Books.

Penrose, R., Shimony, A., Cartwright, N., & Hawking, S. (1997). The large, the small and the human mind. Cambridge, UK: Cambridge University Press.

Peterson, I. (1993). Newton's clock: Chaos in the solar system. New York: W. H. Freeman.

Pinkerton, K. (1994). Using brain-based learning techniques in high school science. Teaching and Change, 2 (1), 44-60.

Pirsig, R. (1974). Zen and the art of motorcycle maintenance. New York: Bantam Books.

Popper, K. (1992). The open universe: An argument for indeterminism (reprint ed.). New York: Routledge.

Prigogine, I. (1996). The end of certainty: Time, chaos and the new laws of nature. New York: The Free Press.

Prigogine, I., & Stengers, I. (1984). Order out of chaos: Man's new dialogue with nature. New York: Bantam Books.

Qualitative research/Grounded theory. [On-line 6/6/98]. Available: http://coehp.idbsu.edu/FACHTMLS/SIEGLE/qual/ground.htm

Quartz, S., & Sejnowski, T. (1996). The neural basis of cognitive development: A constructivist manifesto. [On-line 3/9/98]. Available: http://www.cogsci.soton.ac.uk/bbs/Archive/bbs.quartz.html

Restak, R. (1984). The brain. New York: Bantam Books.

Restak, R. (1995). Brainscapes. New York: Hyperion.

Rocha, L. (1998). Selected self-organization and the semiotics of evolutionary systems. In G. van de Vijver & S. Salthe (Eds.), Evolutionary systems (in press). [On-line 11/1/97]. Available: http://www.c3.lanl.gov/~rocha/ises.html

Roegholt, S. (1993). Towards a concept of multiperspective education. Journal of Curriculum Studies, 25, 153-167.

Rogoff, B., Mosier, C., Mistry, J., & Göncü, A. (1993). Toddlers' guided participation with their caregivers in cultural society. In E. Forman, N. Minick, & C. Stone (Eds.), Contexts for learning (pp. 230-253). New York: Oxford University Press.

Ruiz, A. (1998). The contributions of Humberto Maturana to the sciences of complexity and psychology. [On-line 3/9/98]. Available: http://www.intecocl/contrib/contrib1.htm

Sable, R. (1996). Beliefs, models, and analogies. [On-line 1/24/98]. Available: http://www.gwu.edu/~asc/biographies/Maturana/BMA/matnerv.html

Sable, R. (1996). Symbolic generalizations or definitions. [On-line 1/24/98]. Available: http://www.gwu.edu/~asc/biographies/Maturana/SYMB/matSYMB.html

Scheibel, A. (1997). Thinking about thinking. American School Board Journal, 184 (2), 21-23.

Schiller, D. (1994). The little Zen companion. New York: Workman Publishing.

Schon, D. (1987). Educating the reflective practitioner. San Francisco: Jossey-Bass.

--School Improvement Plan, 1998 Comprehensive, Local Education Plan 1997-2001 (Approved April 6, 1998). (Unavailable because of confidentiality of location).

Schubert, W. (1986). Curriculum: Perspective, paradigm, and possibility. New York: Macmillan.

Seuss, Dr. (T. Geisel). (1993). Oh, the places you'll go. New York: Random House.

Sheperd, G., & Ragan, W. (1982). Modern elementary curriculum (6th ed.) New York: Holt, Rinehart and Winston.

Short, E. (Ed.). (1991). Forms of curriculum inquiry. Albany, NY: State University of New York Press.

Shuell, T. (1990). Phases of meaningful learning. Review of Educational Research, 60, 531-547.

Silverstein, S. (1974). Where the sidewalk ends. New York: Harper and Row.

Skarda, C., & Freeman, W. (1987). How brains make chaos in order to make sense of the world. Behavioral and Brain Sciences, 10, 161-195.

Smith, H. (1958). The religions of man. New York: Harper & Brothers.

Sousa, D. (1995). How the brain learns: A classroom teacher's guide. Reston, VA: NAASP.

Springer, S. (1989, Spring). Educating the two sides of the brain: Separating fact from speculation. American Educator, (pp. 32-37, 52).

Steffe, L., & Gale, J. (Eds.). (1995). Constructivism in education. Hillsdale, NJ: Lawrence Erlbaum Associates.

Steichen, E. (1955). The family of man. New York: The Museum of Modern Art.

Stevens, W. (1942). The collected poems of Wallace Stevens. New York: Alfred A. Knopf.

Strauss, A. (1987). Qualitative analysis for social scientists. Cambridge, MA: Cambridge University Press.

Strauss, A., & Corbin, J. (1990). Basics of qualitative research: Grounded theory procedures and techniques. Newbury Park, CA: Sage Publications.

Sylwester, R. (1994, December/January). What the biology of the brain tells us about learning. Educational Leadership, 46-51.

Sylwester, R., & Cho, J. (1993, December/January). What brain research says about paying attention. Educational Leadership, 71-75.

Taylor, J. (Producer & Director). (1989). The strange new science of chaos. [Videotape]. Boston: WGBH Educational Foundations.

Thomas, G. (1997). What's the use of theory? Harvard Educational Review, 67 (1), 75-104.

van der Veer, R., & Valsiner, J. (Eds.). (1994). The Vygotsky Reader. Oxford, UK: Blackwell.

Varela, F., Thompson, E., & Rosch, E. (1991). The embodied mind: Cognitive science and human experience. Cambridge, MA: MIT Press.

von Glasersfeld, E. (1995). Radical constructivism: A way of knowing and learning. London: The Falmer Press.

von Glasersfeld, E. (1996, April). Cybernetics and the art of living. Plenary address at the 13th European Meeting on Cybernetics and Systems Research, Vienna. [On-line 3/9/98]. Available: http://www.networld.it/oikos/Vonglas2%20oct.htm

von Glasersfeld, E. (1996, September). The conceptual construction of time. Paper presented at Mind and Time, Neuchâtel. [On-line 1/25/98]. Available: http://www.networld.it/oikos/Vonglasoct1.htm

von Glasersfeld, E. (1998). Homage to Jean Piaget (1896-1980). [On-line 3/9/98]. Available: http://www.oikos.org/Piagethom.htm

Waldrop, M. (1992). Complexity: The emerging science at the edge of order and chaos. New York: Simon & Schuster.

Wang, M., Haertel, G., & Walbertg, H. (1990). What influences learning? A content analysis of review literature. Journal of Educational Research, 84, 30-43.

The way: An illustrated edition of *The Living Bible* (1972). Wheaton, IL: Tyndale House.

Webster's new world college dictionary (3rd ed.). (1997). New York: Simon & Schuster.

Webster's ninth new collegiate dictionary. (1989). Springfield, MA: Merriam-Webster.

Whitaker, R. (1996). Autopoiesis and enaction. The Observer Web. [On-line 6/14/98]. Available: http://www.informatik.umu.se/~rwhit/AT.html

Whitsel, B., & Kelly, D. (1988). Knowledge acquisition ("LEARNING") by the somatosensory cortex. In J. Davis, R. Newburgh, & E. Wegman, E. (Eds.). Brain structure, learning, and memory (pp. 93-131). Aaas Selected Symposium, No. 105. Boulder, CO: Westview Press.

Wilber, K. (Ed.). (1982). The holographic paradigm and other paradoxes: Exploring the leading edge of science. Boston: New Science Library.

Wolf, F. (1989). Taking the quantum leap: The new physics for non-scientists (Rev. ed.). New York: Harper & Row.

The World Book Encyclopedia (Vol. 12). (1976). Chicago: Field Enterprises Educational Corporation.

Wood, D. (1992). Old turtle. Duluth, MN: Pfeifer-Hamilton.

Zukav, G. (1979). The dancing wu li masters: An overview of the new physics. New York: Bantam Books.

Zukav, G. (1989). The seat of the soul. New York: Simon & Schuster.

APPENDIX A

Questions for Indepth Interviews

1. Can you tell me briefly about yourself and your interests?
2. How would you describe your school experience?
3. What is your mathematical background?
4. Why did you enroll in this class?
5. Can you describe your overall feelings about the class in general?
6. How do you feel specifically about trig?
7. Can you describe what it means to you to learn trig?
8. How would you describe your personal experience of learning?
9. Is learning trig the same as learning any other academic subjects?
10. Is learning trig the same as learning things outside school?
11. Do your feelings change as you learn?
12. How do you know if you learned something?
13. Define learning.

APPENDIX B

Sample Interview, Student XV

Female Caucasian (only senior in the class)

*** Indicates a probing or clarification question from interviewer

1. Can you tell me briefly about yourself and your interests?

Well, I'm 17. My interests, they are all based on science and chemistry. I want to be a chemical engineer and that's what I've planned for college and the rest of my life, my career. I have a large family. They've helped me with everything I do. I make pretty good grades. If I applied myself more, I could probably make better grades but I'm just busy with everything.

***

[Gave a lot of detail about a fairly complicated family with real brothers and sisters, step-brother and half brother.]

He lives in Washington state. When I was growing up, I barely ever got to see him. And then it got kinda of strange. When we moved to Oklahoma, he suddenly realized that he had some kids he might want to see....[continued to narrate an estranged relationship but with positive descriptions]. I see him about every summer except the last summer I was in Virginia so I didn't get to see him.

***

I was born in Oregon, but only lived there a week....(laughs). I lived in Washington for 7 to 8 years, then Alaska for 7 years and I have lived here for 2 1/2 - 3 years.

***

Started freshman year in Alaska. They are a lot different. There's more money to be spent on different things. What I did in Chemistry I, we did in 7-8 grade. They were more progressive. They had a lot of harder teachers, that I don't know, I know all teachers want to teach, but these teachers were really intense (laughed). There were a lot of different programs you could take.

***

I got into Chem I and [Chemistry teacher] in his own strange way affected that. He gave me a lot of confidence where I didn't think I could do some of the things and he would just say a couple of words to me and make me want to go a little bit farther. And I just <u>liked</u> it and I liked doing it. I liked figuring out the problems and if I had to spend three hours on one problem, I would do it. It's not like something I didn't like to do. So he influenced me to go into chemistry and this summer I decided to be a chemical engineer.

***

Because I worked at NASA at Langley.

***

My dad works for experimental aircraft and that's his whole company is based around that. He had a friend who was a contractor for NASA and he told my dad about a program that lets high school students work there. So I applied for the program, and they said I couldn't be in the program because I was out of state. So I reapplied, and they said well, they looked at everything I turned it and said it would be good if I worked there but you can't be paid...So I volunteered.

***

...It's really interesting...There's a lot of intelligent people and it really rubs off on you. You find yourself talking about it...You get there and people are talking about Reynolds numbers and this that and you're going "Huh?" And then by the end of the time I adapted to it. I got a feel for it and they didn't treat me like a little kid here volunteering. They didn't make me go fetch them coffee or anything. They had me doing exactly what they did.

***

Two months.

2. How would you describe your school experience?

I like this school a lot better than I liked the Alaska's school. The people are nicer and it makes you more comfortable to work when they are nicer, when they aren't out to get you or anything. It's just been, sometimes it's gets really boring, and I can't wait to leave and then sometimes...It's hard to explain how it's been. It's worked.

***

The most positive experience I ever had was in ... Chem II class. And there were five people chosen to take college chemistry. And three were seniors - guys - one was a junior "guy" and me. And I was only female chosen for this class.

***

After a quarter of chemistry, we went to College Chemistry. These guys were always very smart and had made 34's on their ACT's and they just thought they owned the world.

And they were always putting me down, like "You can't do that. You don't know what you're talking about." And so, I went up to ask [chemistry teacher] and he said, "You know how to do this."

"But, [chemistry teacher] I haven't done this."

"Just go back. You know how to do this."

"But those guys. They keep giving me a bad time."

"Don't listen to them. You know more about it than they do. You can do it."

I went back, and I did it, and I was so proud of myself. That carried over and he chose me as the most outstanding Chem II student over all those really egotistical seniors who I always thought were so much smarter than me. Then I beat them in the Science fair after they told me I couldn't do it. And so that was probably the best, so I thought, "Victory for me and victory for all the girls who get put down."

***

[Negative]

No. I would have to think about it. I'm sure there was one, but I can't remember. I've never had. I negative time for me would be getting an "F" or a teacher not being satisfied with what I'm doing. If a teacher was really disappointed in me, that would be a negative time. I don't recall them; maybe I block them out. (pause). I can remember a sad one when I was running for senior vice-president. [Told details of losing the election.]

***

I'm the only senior in that class.

***

I am going to apply at two places - University of Washington and Colorado School of Mines. [Gave reasons why and then talked about her ACT scores - 28 composite.]

3. What is your mathematical background?

I've taken everything except Calculus and Algebra III. I took regular Algebra my freshman year and I decided that was too slow filled with people who don't get the basic understandings. That just frustrates me, so I asked my teacher if he would put me in AP and he would. It won't do anything for me, like Calculus and things like that. It just gets me going faster; we cover more; we have people asking intelligent questions instead of dumb ones....

***

This year. I have Honors English IV, Physics, Government, Spanish III and Trig and I'm an aide (laughs) sixth hour.

***

[In Alaska, did you do special things with math?]

There, we had this thing in elementary school called PACT. It was the Program for Academically and Creative Students. I always got bored in the regular classes so I never did them and so they said, "We don't think you're good enough to go into Pre Algebra I in the seventh grade." That kind of messed it all up....

4. Why did you enroll in this class?

Cause it was the next step in math. I can't imagine not taking math for four years or stopping with Algebra I or Geometry. [with this same group in Geometry]

5. Can you describe your overall feelings about the class in general?

Trig? I liked the other math classes. I don't know if it's [Mr. Sine] or if it's the other teacher, but I just <u>don't like</u> - I'm getting tired of it all. Maybe it's because I'm getting ready to graduate or what. I'm just getting tired of it. (laughs) I know how to do it; I'm just don't like doing my work. Guess, I'm just lazy. I've never been like this. I've always had my work done and worried about when I get it done and now, I just don't think about it.

***

Not the construction of the class. Not the class at all. It's just me. Maybe it because all of our other teachers have always given us a basic description of what we're doing and given us a couple of notes and that's it. They stop right there and they let us go on our own. And [Mr. Sine] just talks and talks and talks and talks (laughs).

6. How do your feel specifically about trig?

Pretty easy. If I don't do some work and have to make it up, I make up the work all in one night. I rarely study for the tests. Maybe I just pick it up when I'm listening or when I'm doing my work or catching up with my work. I make A's on the tests. Trig itself is not that hard. I'm just frustrated, I guess.

7. Can you describe what it means to you to "learn" trig?

Well, it means to me that I can pass the tests. It's just not, I know I have to learn it to be able to do what I want to do in life. I'm just not interested in it like I am in all my other classes. The ones that I really excel in are the ones I really enjoy, I like. I like doing them. Even if the teacher is bad, I ignore the teacher and do them. And, I don't know -- I just don't like it like [other math classes.]

***

Just kinda bored with the class.

***

I get really happy with myself when I ever figure out anything in any of my school or after school activities. When we were doing the identities like last year, almost the first quarter we had taken last year because we had finished our whole Algebra II book....I can remember doing the identities and as soon as I understood them, I thought these were really fun. I liked doing them...solve, prove them. It kind of blew the whole first quarter. I liked doing the identities and I keep on liking the identities but this year, I haven't found anything I like doing. It all seems to be the same thing. Just little variations on what we have already learned.

8. How would you describe your personal experience of "learning"?

It's been good. I like learning. That's why I want to go into science rather than something else. It used to be I wanted to be a corporate lawyer. And anything I put my mind into, I know I can do well. I may not be the best, but I would like to be the best at something later on in my life. With law, you just can't <u>learn</u> any more. You are battling the same things over and over and arguments and stuff. In science there's always room to find something new or find something different about this or just ... there's <u>room</u> to learn and that's the reason why I chose it.

9. Is "learning" trig the same as learning any other academic subjects?

It's the same but I don't like it as much as I like it as much as other things.

***

I still have to do the same things. I have to learn something new, I have to do the work, I have to take the notes and take the tests, but maybe there's still room left to get excited about it and something. In trig, all my room is taken up.

10. Is learning trig the same as learning things "outside school"?

No. I usually learn my things outside of school by experience, by making mistakes and fixing them, and in trig I learn it because I have to learn it, but... These other things I have to learn, but I learn in a different way. Like in my job I learn it by getting feedback from people I do things for and they're telling me what I can do better and what I am doing well. In trig you know what it is, you don't have the constant feedback except for maybe grades and I don't consider that the same as people talking to you.

11. Do your feelings change as your learn?

Feelings about what? About everything? About learning? Yeah, they do. Because I can see myself when I'm not liking something or am frustrated or not doing as well as I like it affects me. I can understand like how people who fall behind in classes how they don't ever pick themselves up because it takes such extraordinary effort to get yourself out of the rut you got yourself in. They, the more you don't do what you are supposed to do, the more you don't understand or fall behind, the more you want to give up. Like in trig, sometimes that happens to me like if I don't do an assignment and then I just sit in class for the rest of the day and not do anything. If you are doing your work, you're doing all right and hey, this is OK. I handle this.

***

I know what you're saying. This doesn't have anything to do with trig at all. Because you know....In chemistry, when I was in college chemistry, there were these problems and they were the hardest problems you could possibly do in the book. I am sitting here in my room on my desk and I have all my information down that I need. Ok, how am I going to do this? And it took me three hours to get this problem done. I just sat in my room. Didn't eat dinner, didn't do anything and I just looked at the problem and tried it and erased holes in my paper and everything trying to figure it out. Finally I got it! Like I jumped out of my room and my sister was already asleep because it was so late at night. Did a little dance around the room and everything. It made me so excited and I went back to class. Mr. [XXX], I got it, I got it. It took me so long! It makes me want to go on to something new and try to do it again and go back to the problems I didn't think I could get and then I try them again. And it gives me just a little more energy to go on and not give up on the problems. [Rate of speech even picked up she was relating this event]

12. How do you know if you "learned something"?

Because I can relate it to other things I'm doing. I mean I can do something in class and get it, but if I can't find some little place for me to use it, I don't think I've learned it.

***

[time limit?]

No. Because I've done things and I don't really recall them but I know I have done them and I have reflected back on when I did that in class or when I've did that someplace else and it's helped me out later on. Way far away....Like it could be "Jeopardy." Like I could be watching "Jeopardy" and taking a class when I was a freshman and all of a sudden the answer comes out of nowhere and I know it's not because I read it that day. It's because I learned it and kept it safe in my brain because I thought it was important enough for me to keep in my brain.

13. Define learning.

Well, I think it was just what I was talking about. I think learning is when you are introduced to something new, something you don't know about and you get an understanding of it and then you use it. Then you use it. You capitalize on what you've just been told or just been introduced to and it stays with you. It's like Algebra. You always hear about people who say, "Uh, when are we going to use Algebra in later life!" But you use it all the time. Geometry. A lot of the things. I think it just stays with you--all the time.

APPENDIX C

Demographic Information of Indepth Interviews

1.	**GENDER:**	Male (6)	Female (9)
2.	**RACE:**	Caucasian (11)	Vietnamese (4)
3.	**GRADE:**	Freshman (1) Junior (13)	Sophomore (0) Senior (1)
4.	**TIME OF INTERVIEWS:**	7:30 a.m. (10)	3:30 p.m. (5)
5.	**RESIDENT IN DISTRICT:**	Since kindergarten (10) Transfer (3) N/A (2)	
6.	**FAMILY:**	Traditional (8) N/A (2)	Non-traditional (5)
7.	**EDUCATIONAL LEVEL OF PARENTS:**	College degree (1) N/A (5)	High school (9)
8.	**INTERESTS:**	Academic (6) Sports (3)	Musical (8) Other (9)
9.	**DAILY HOMEWORK:**	2 or more hours (3) Less than 1 hour (1)	1 - 2 hours (1) N/A (6)
10.	**ATTITUDE TOWARDS TEACHER:**	Favorable (6) N/A (4)	Unfavorable (5)

11. ATTITUDE TOWARDS CLASS:

Favorable (10)	Unfavorable (4)
N/A (1)	

12. ATTITUDE TOWARDS MATH IN GENERAL:

Favorable (8)	Unfavorable (5)
N/A (1)	

13. REASONS FOR LIKING CLASS:

Social (5)	Subject (1)
Teacher (3)	Uncomfortable (1)

(Question not given to all students)

14. REASONS GIVEN FOR LIKING/DISLIKING MATH:

Algebra better (2)	Pretty easy (1)
Not fun (1)	Hard (2)
Difficult (1)	Practical (1)
Bizarre (1)	Not Practical (2)

(Question not given to all students)

15. ENROLLED IN ADVANCED MATH PROGRAM:

From 8^{th} grade (8)	Other (7)

APPENDIX D

Behavioristic vs. Chaos Descriptor Incidents

Student	Behavioristic	Chaos
I.	9	16
II.	23	1
III.	15	16
IV.	8	12
V.	5	11
VI.	7	9
VII.	6	9
VIII.	8	2
IX.	5	10
X.	3	14
XI.	3	4
XII.	13	6
XIII.	8	6
XIV.	10	10
XV.	9	8
TOTAL	**136**	**144**

Note: This matrix is an example of the initial coding procedures utilizing grounded theory constructs. When these interviews were taken, the initial coding was done by comparing chaos theory and behaviorism. Although the information was helpful, there were no indicators that a learning theory could be totally supported by chaos dynamics.

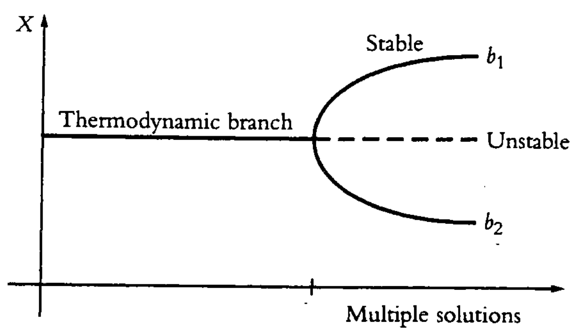
A later review of the interviews indicated that complexity theory was also applicable and the incidents were subsumed under the complexity theory framework.

An incident was defined and coded during a question or a probe question interval, one per question. The students were not familiar with the terms chaos or behaviorism. Often the student would pair a behavioristic and a chaos explanation to contrast examples. Nine students used more chaotic incidents; five had more behavioristic incidents.

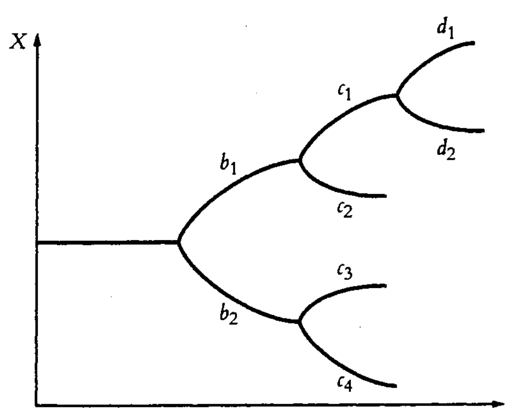
APPENDIX E

Pitchfork Bifurcation and Successive Bifurcations

(1) At the bifurcation point, the thermodynamic branch becomes unstable, and the two new solutions b_1 and b_2 emerge.



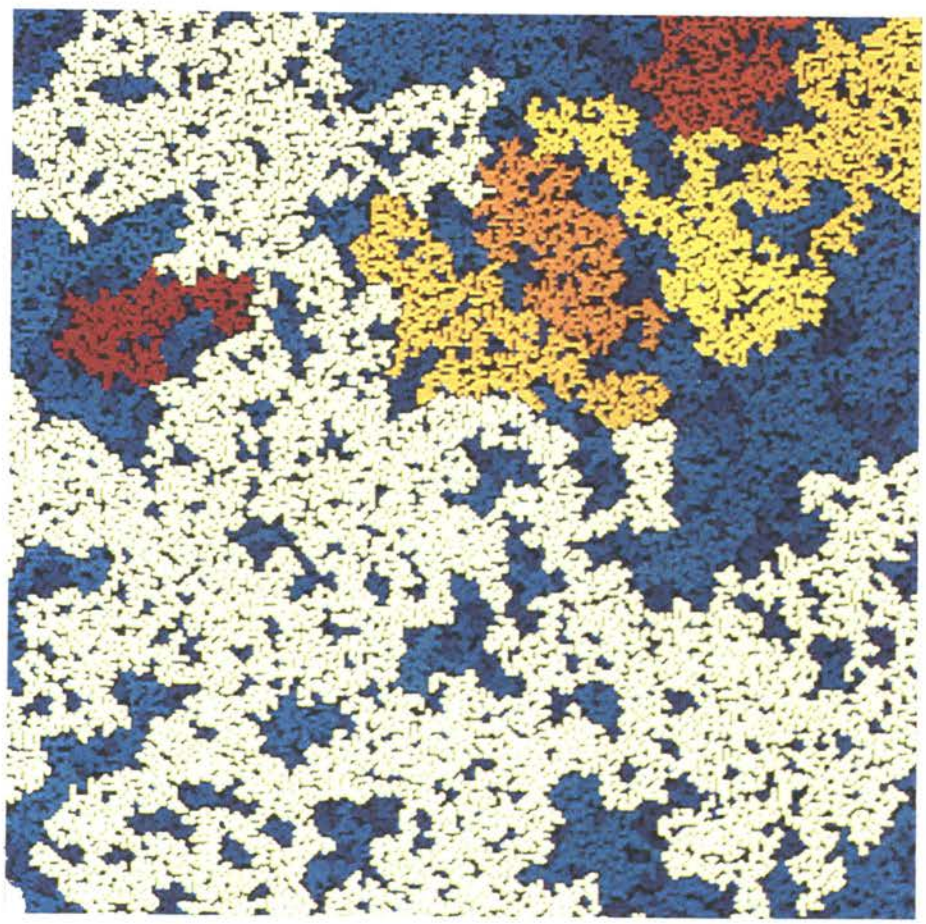
(2) Successive bifurcations occur with increasing distance from equilibrium.

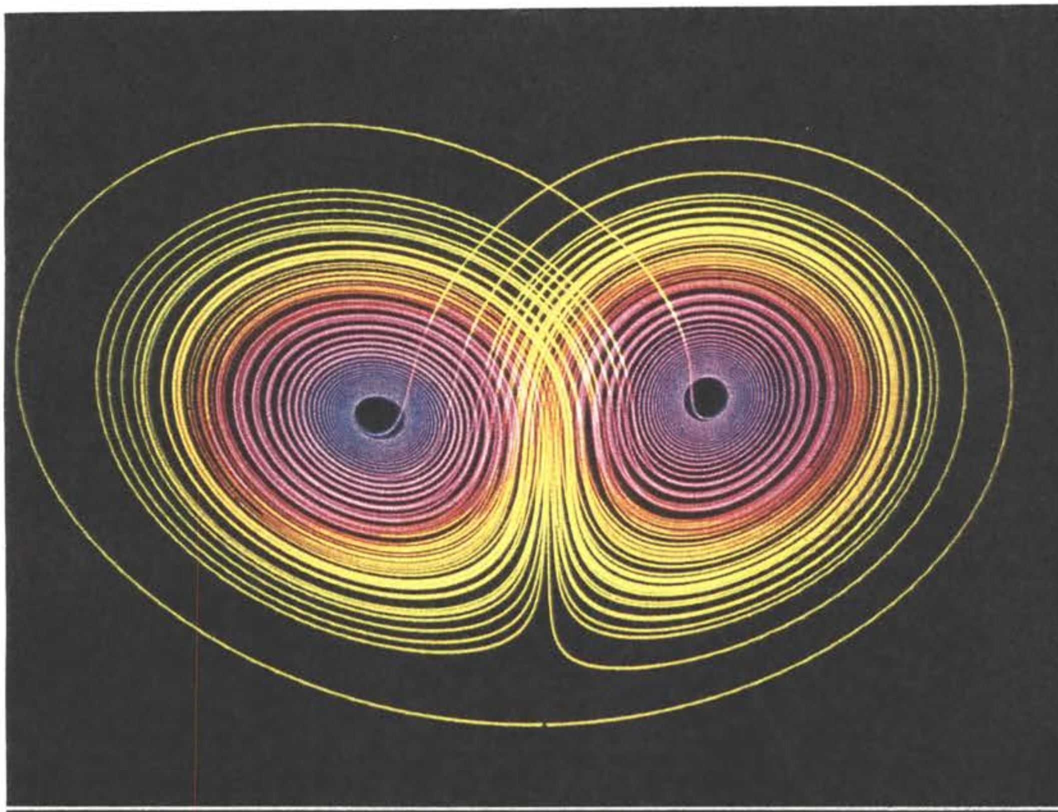


APPENDIX F

Fractal Elegance

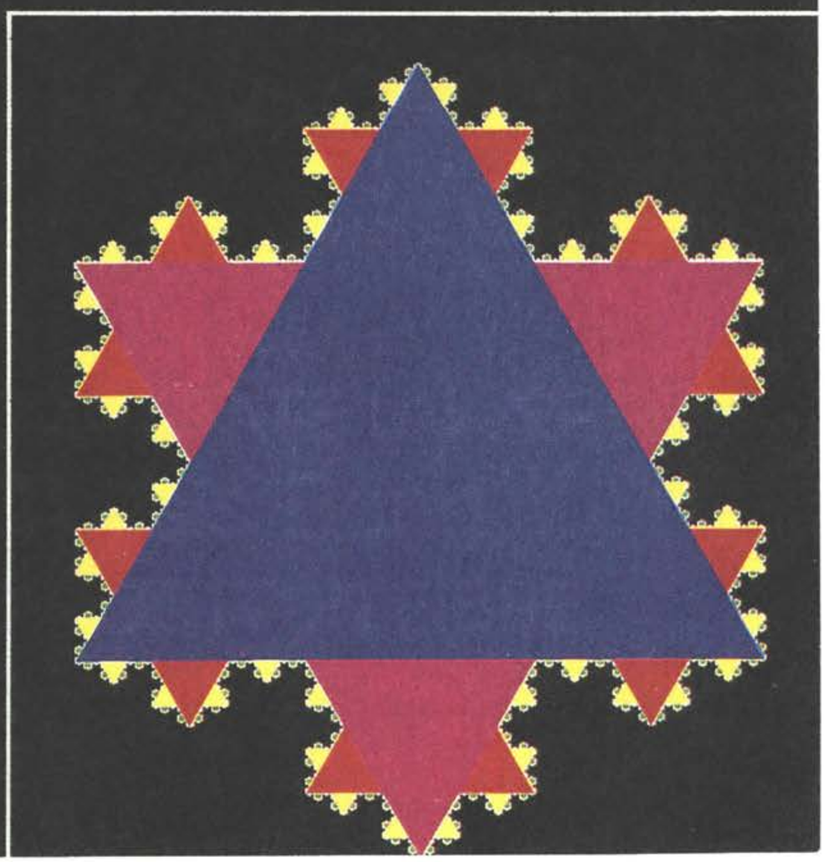
Figures of the fractal clusters, the Lorenz attractor, the Koch curve and the Mandlebrot set were taken from an insert, N. Hall (1991), (Ed.), Exploring Chaos: A Guide to the New Science of Disorder, unnumbered pages.

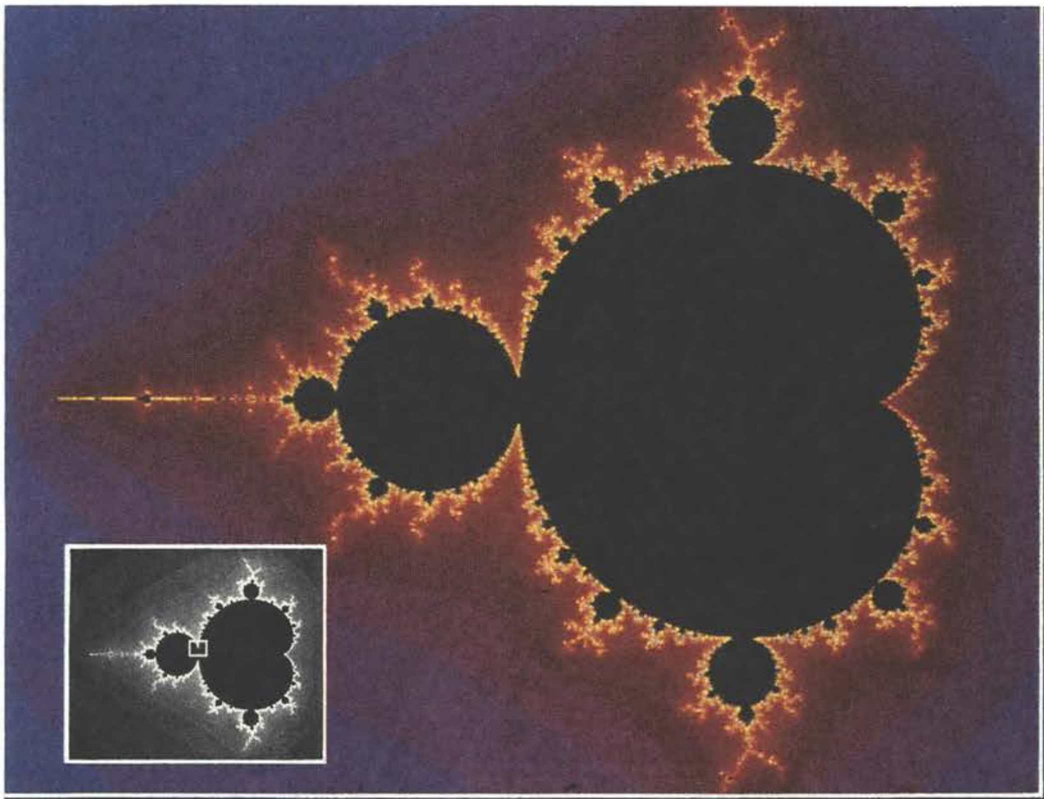




The Lorenz attractor.

The Koch curve.





HEINZ-OTTO PEITGEN PETER H. RICHTER

THE MANDELBROT SET. A voyage through finer and finer scales shows the increasing complexity of the set, with its seahorse tails and island molecules resembling the whole set. By the last frame, the level of magnification is about one million in each direction.

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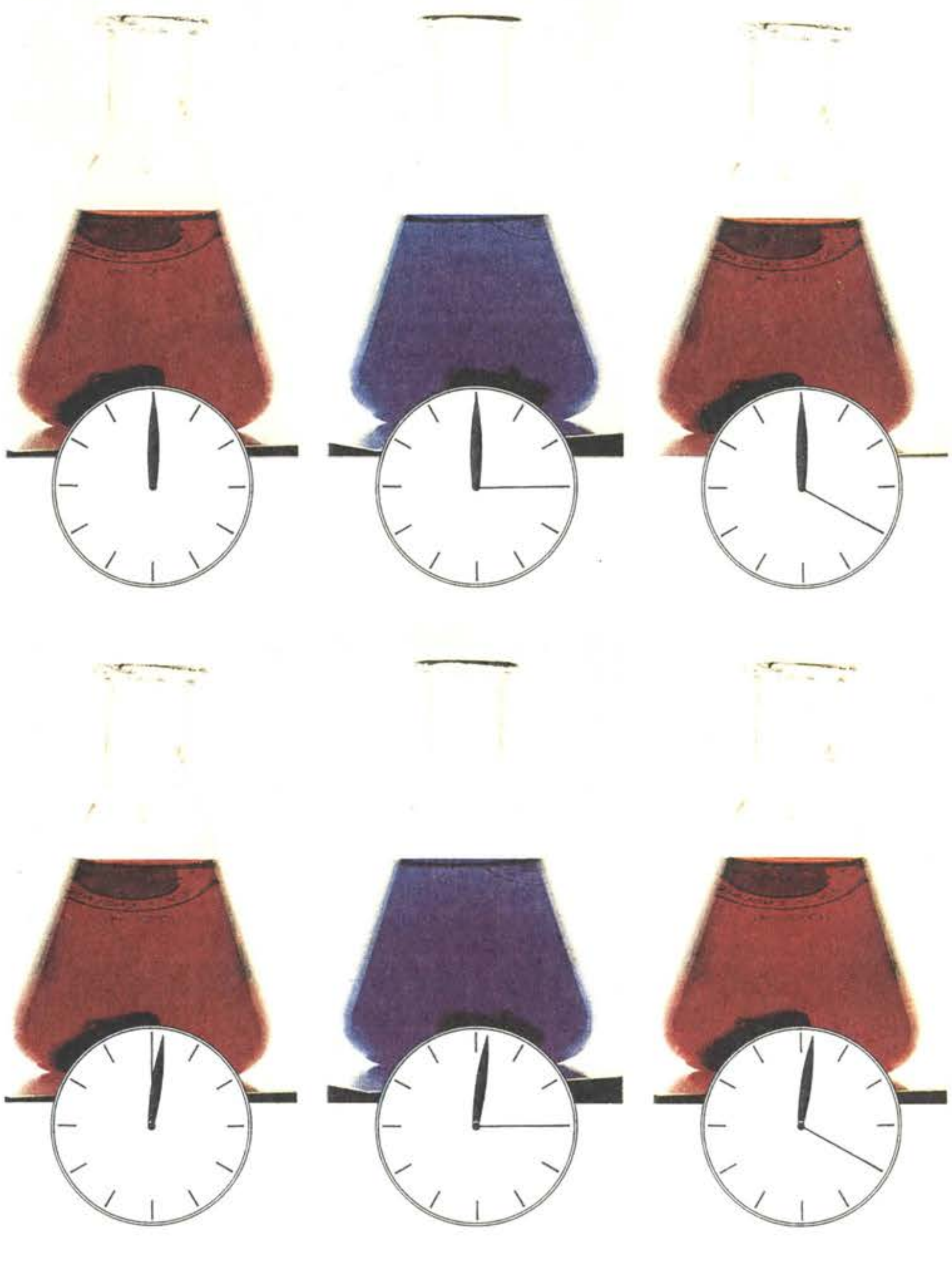
APPENDIX G

The Belousov-Zhabotinskii Reaction



This figure showed the oscillations in the Belousov-Zhabotinskii reaction, a chemical example of dissipative structure. Noted was the periodic change between red and blue, shown over a period of about 80 seconds. Because of nonlinear iteration of the chemical reaction, random or chaotic molecular motion spontaneously transformed structures in space and time. Metaphorically, the slightest fluctuation in the red part became magnified and catalyzed production of more red molecules. The red chemicals first built up in one region of the solution; then the blue prevailed. Macrostructuring of the different chemicals resulted. Order emerged out of chaos because energy was constantly supplied by the chemical reaction in its self-organization.

This figure was taken from Plate 14, (insert), N. Hall (1991), (Ed.), Exploring Chaos: A Guide to the New Science of Disorder, unnumbered page.

APPENDIX H

Three Traditions of Cognitive Science

	Cognitivism	Emergence	Enactive
Metaphor for the Mind:	Digital computer	Parallel distributed network	??? Inseparable from experience and world
Metaphor for Cognition:	Symbol processing	Emergence of global states	Ongoing interaction within the medium
The World in Relation to Us:	Separate objective	Separate objective	Engaged "brought forth"
	Representable (in symbols)	Representable (in patterns of net-work activation)	Presentable (through action)
Mind vs. Body/World:	Separable	Separable	Inseparable
	Cartesian dualism-- (mind and body hermetically sealed from each other)	Epiphenomenal-- (mind related to body and world via emergence)	Phenomenology— (mind and world enacted in history of interactions)
Exponents:	Simon, Newell, Chomsky Fodor, Pylyshyn	Rumelhart, McClelland, Dennett, Hofstadter	Maturana, Lakoff, Rorty, Piaget, Dreyfus

(Based on Varela, Thompson & Rosch, 1991 as cited in Whitaker, 1996, pp. 15-16)

VITA

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Doctor of Education

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